AD-774 303

ROLL OVER PROTECTIVE STRUCTURE (ROPS) DESIGN, ANALYSIS AND TEST FOR THE MILITARY 6000-LB. ROUGH TERRAIN FORK-LIFT TRUCK

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Lockheed Propulsion Company

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FINAL REPORT
15 JANUARY 1974

Contract No. DAAK02-72-C-0574
U.S. Army Mobility Equipment
Research and Development Center

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Technical Director

LOCKHEED PROPULSION COMPANY

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1.0 INTRODUCTION

This document is the final technical report summarizing technical performance on Contract No. DAAK02-72-C-0574 for roll-over protective structure (ROPS) retrofit to the Military 6000-Pound Rough-Terrain Forklift Truck. A ROPS has been developed, which by utilizing a two-post design and a wire mesh roof, provides minimum obstruction to operator visibility. The structural capability has been demonstrated by compliance with SAE static load testing requirements and by a field roll-over test.

The program was structured as a two-phase effort to develop a ROPS for the forklift truck. The tasks of the development phase were as follows:

- o Examine the vehicle chassis in the areas of ROPS attachment for structural adequacy and determine methods of reinforcement if required.
- o Design and analyze structurally a ROPS which can be retrofitted to the forklift truck with a minimum of impairment to the functional requirements of the vehicle.
- o Fabricate a development unit and conduct a test to applicable SAE Recommended Practices to obtain data required to verify the ROPS design.

The prototype phase of the program was conducted with the following tasks:

- o Analyze the development test results, modify the development ROPS design and conduct additional structural analysis as required to establish a prototype design.
- o Fabricate a prototype unit and perform a certification test to SAE Recommended Practices.
- o Conduct a field roll-over test to verify the design under actual roll-over conditions.
- o Fabricate two additional units to be delivered to USAMERDC. The first to be installed on a Type "A" vehicle while documenting installation procedure. The vehicle will then undergo performance testing at USAMERDC. The second ROPS is to be used as an installation trainer at USAMERDC.
- o Prepare a complete technical data package for producing and installing ROPS and ROPS adapters for the forklift truck.

This is the first of three final technical reports due under this contract. The remaining two reports will be submitted following the completion of the respective technical efforts and will cover the following vehicles:

1. Clark 290M and Caterpillar 830MB military medium-wheeled tractors.

2. Military 10,000 pound rough-terrain forklift truck, Allis-Chalmers 645M military front-end loader, J. I. Case MW24 military front-end loader and military 20-ton rough-terrain crane. The development of the non-linear computer program will be included.

This final report fulfills the requirements as specified in DD Form 1423 and contains a summary of information generated throughout the program and incorporated previously into the monthly progress reports, preliminary design review (PDR) and critical design review (CDR).

2.0 SUMMARY

A roll-over protective structure (ROPS) for the Military 6000 Pound Rough-Terrain Forklift Truck was developed and is shown in Figure 1. All objectives of the contract were met. In arriving at these objectives, development and prototype hardware were designed and analyzed structurally, four units were fabricated, and three tests were conducted including a field roll-over test. The design was certified to meet applicable SAE criteria. A complete technical data package capable of producing and installing ROPS and adapters to the vehicle was provided.

2.1 Design

The design effort included feasibility studies and complete drawing packages for the development and prototype hardware. The results of the feasibility studies indicated that a two-post configuration attached to the vehicle aft of the hydraulic reservoir would provide the best retrofit advantages. The ROPS is fabricated with square tubing with gusseted corners and provides overhead falling object protection (FOPS) with steel mesh while maintaining minimum obstruction to operator visibility. The ROPS fits into sockets and is attached by two cap screws. Since the forklift was not originally designed for ROPS installation, reinforcements were required to distribute loads into the chassis.

Although the development design met all structural requirements, the objectives of the prototype design phase were to solve two problems encountered with the development hardware. Fit checks to the Type "A" vehicle with wooden mock-ups showed inadequate clearance with the steering actuation system and with the tires during some modes of operation. Also, lengthy installation time and chassis distortion were encountered during welding of reinforcements to the chassis. Modifications made to the post feet, sockets and chassis reinforcements provided adequate clearance in all areas. A bolt-on concept was developed which simplified the installation procedure and did not require welding to the chassis. Reinforcement of the axle housing was no longer required since a cross-over beam was provided to transmit loads between sockets.

2.2 Structural Analysis

Comprehensive structural analyses were conducted to assure structural integrity of the ROPS and vehicle to withstand roll-over loads. The applicable SAE standards and the anticipated roll-over conditions were used to establish the applied loads. The non-linear plastic computer program developed by LPC and classical techniques were used to perform the analyses. The analysis results indicated that all areas of the structure could withstand the applied loading environment with adequate safety factors. Deflection curve predictions for side and vertical loading were developed prior to each test and compared to measured results after the completion of each test.

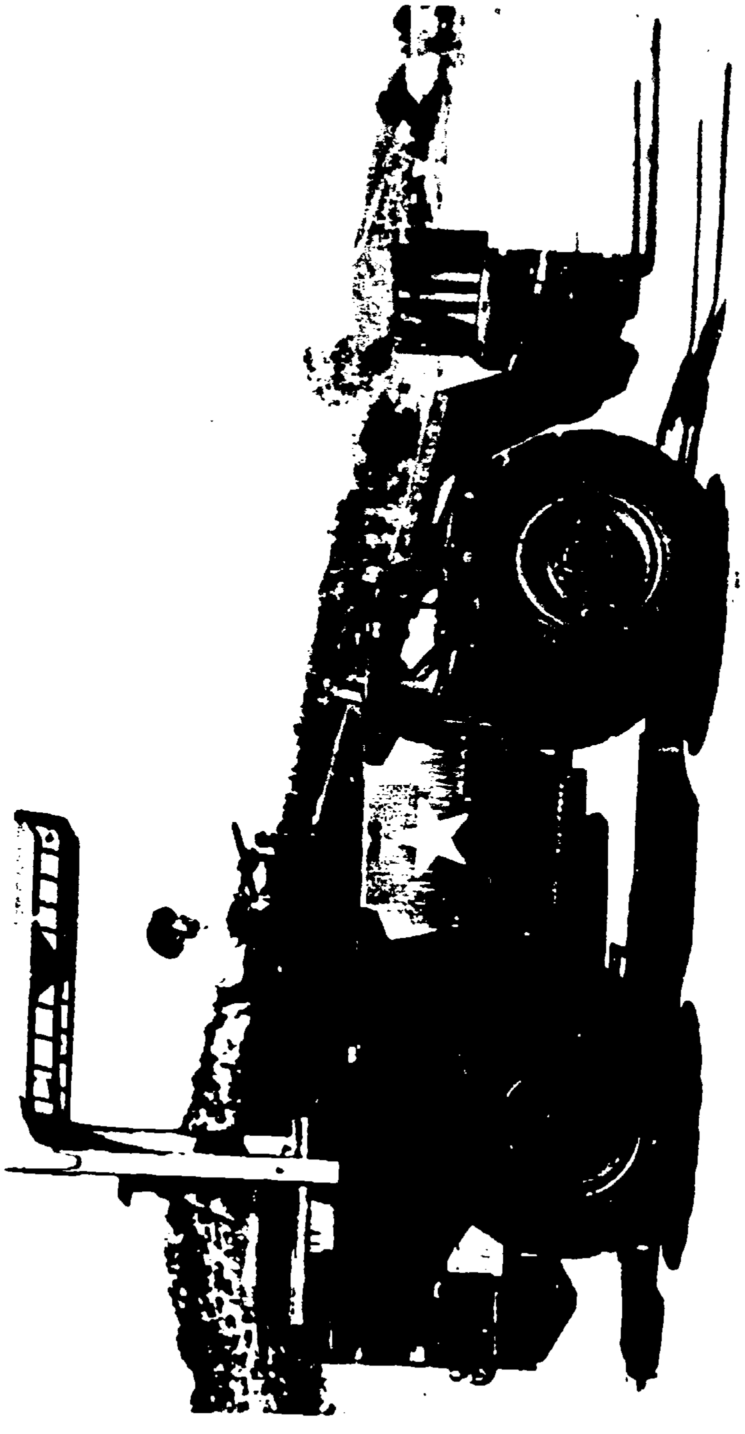


Figure 1 - 6K Forklift with ROPS

2.3 Fabrication

Four ROPS units were fabricated during this contract. All of the units were built by Tube-Lok Products, Portland, Oregon following the solicitation of competitive bids by LPC. The following is a summary of the hardware procured and its usage:

(1) Development test unit

(2) Prototype test unit which was also used for the field roll-over test

(3) Delivery unit which was mounted on Type "A" vehicle and shipped to USAMERDC for performance testing

(4) Delivery unit which was shipped to USAMERDC for use as an installation trainer model.

2.4 Testing

A series of three tests was performed at the Lockheed Potrero test facility to demonstrate that the unit could meet loading requirements. This series included a development, prototype and field roll-over test. The development and prototype tests were conducted in accordance with the following applicable SAE Recommended Practices:

- The 500-lb weight dropped 17 feet FOPS requirement of J231
- The 15,000-lb side load, 122,000 in-lb side load energy, 2?,500 lb vertical load and 8 ft-lb Charpy V-notch strength requirements of J394a.
- The critical zone limitations of J397a which permit deflection of 13.5 and 14.5 inches in the horizontal and vertical directions, respectively.

The objective of the development test was to obtain data required to verify the ROPS design. The test results showed that the unit passed successfully all SAE requirements specified above. However, problems of lengthy installation time and vehicle chassis distortion were encountered during welding of reinforcements to the chassis.

The second test was conducted to certify the final prototype design would meet the requirements of the applicable SAE Recommended Practices. The tests of the bolt-on unit demonstrated compliance with requirements. The formal test report of certification to SAE standards is included as Appendix 6.6.

The field roll-over test was conducted with the ROPS used previously in the prototype certification test. The roll sequence included a side roll followed by a complete end-over-end roll. Figure 2 shows the vehicle during the test. The adequacy of the two-post was substantiated by the severe conditions imposed on the ROPS in the roll test.

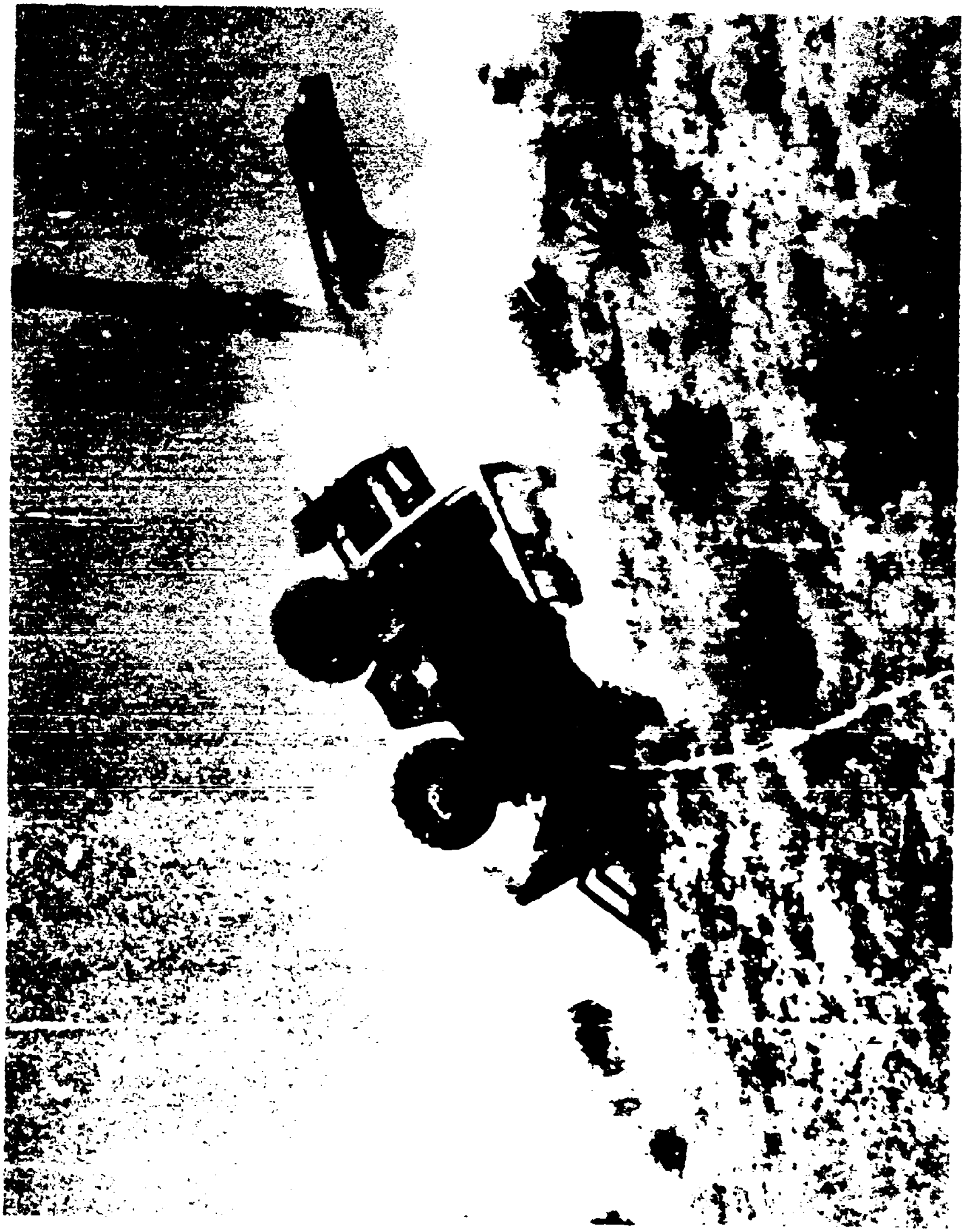


Figure [illegible] - 6K Forklift During Rollover Test

3.0 CONCLUSIONS

A ROPS was developed for the Military 6000-Pound Forklift Truck and certified by test to meet the SAE Recommended Practices. In addition to fulfilling this primary objective, several other important conclusions were reached.

The structural integrity of the ROPS was verified by a field roll-over demonstration. The two-post design concept, with many functional advantages over the more conventional four-post configuration, was substantiated under severe roll-over conditions incurred during the test.

The feasibility of retrofitting a ROPS to the current forklift truck was established. The prototype unit was installed on a Type "A" vehicle and the vehicle reworked to original functional capacity.

Analytical advances were made for predicting ROPS deflection behavior in the elastic and plastic regions. Improvements were made to the non-linear computer program to predict ultimate plastic behavior of the structure. The critical parameters for accurately predicting elastic deflections were identified by resolving differences between analytical predictions and test results.

4.0 RECOMMENDATIONS

The drawings, specifications and installation procedures for the prototype ROPS are acceptable for use in procuring production quantities for the U.S. Army. Since the ROPS is a critical safety item, it is recommended that the units be procured from a manufacturer with a demonstrated capability for producing ROPS in production quantities.

Study of the test results, structural analyses and fabrication information developed in the program indicates that modification of the design approach would result in a ROPS system that is simpler and, therefore, of lower cost than the prototype design. If the number of units expected to be fitted with ROPS justifies the effort, it is recommended that work toward the lower cost design be considered.

It is also recommended that the material specifications included in Appendix 6.1.1 be revised to delete the requirements for ASTMA 516, Grade 65, or Grade 70 steel. The material specifications, EMSD103 and EMSD104, include all necessary material requirements. In addition, the Charpy impact test requirements of the proposed SAE combined ROPS code are an acceptable substitute for the requirements currently included in the specifications.

5.0 DISCUSSION

5.1 Development Phase

5.1.1 Design

5.1.1.1 Design Criteria

The criteria used for design of the ROPS for the 6000-lb rough terrain forklift truck was established to achieve the following goals:

- o Provide adequate roll-over and falling object protection for the operator of the vehicle
- o Minimize the restrictions to the functional characteristics of the vehicle

To meet these goals, it was necessary to develop a design which minimized obstruction to operator visibility, forklift performance degradation and vehicle modifications during retrofit. Since during military use the ROPS and vehicle will be shipped separately, it was desirable to provide for nesting capability and tolerance control to permit interchangeability. Simple and proven design/fabrication techniques were required to achieve a design which could be built for a low unit cost during production.

The load, energy and material requirements are derived from SAE Recommended Practice J394a which specifies the minimum performance criteria for roll-over protective structures for wheeled front-end loaders and wheeled dozers. The J394 practice was selected as the test criteria since the operation and usage characteristics of the rough terrain forklift resembles closely that of the wheeled front-end loaders. A summary of these requirements is presented in Figure 3, SAE Design Criteria.

The gross vehicle weight is 23,500 lb and corresponds to the vertical load requirement. The side load and side load energy requirements of 15,000 lb and 122,000 in-lbs respectively, are derived from the empirical equations specified in J394a. The current specification requires that for two-post designs the side load should be applied at a point 1/3 of the roof length from the vertical posts or, 20.7 inches. However, since the distance to the critical zone is greater than 1/3 of the roof length, an alternate requirement seemed appropriate. On the recommendation of the SAE Ad Hoc Committee on 15 March 1973 the side load application point was established as the aft limit of the critical zone. This distance is 37.0 inches from the centerline of the vertical posts for this ROPS unit, and was the location used for the side load application.

The deflection limits were established from SAE Recommended Practice J397a which specifies the critical zone for laboratory evaluation of roll over protective structures and falling object protective structures of construction and industrial vehicles. As shown in Figure 4, the deflection limits at the aft edge of the critical zone are 13.5 and 14.5 inches in the horizontal and vertical directions, respectively. The horizontal deflection limit was established in accordance with Section 5.3.2 of J397a by determining a simulated ground plane (SGP), rotating this plane 15 degrees away from the critical zone

- FORKLIFT WEIGHT, W — 23,500 LB

- SIDE LOAD, F — 15,000 LB

$$F = 5300 \left[\frac{W}{10,000}\right]^{1.22}$$

- SIDE LOAD ENERGY, U — 122,000 IN-LBS

$$U = 42000 \left[\frac{W}{10000}\right]^{1.25}$$

- VERTICAL LOAD, W. — 23,500 LB

- MATERIAL IMPACT STRENGTH — CHARPY V NOTCH STRENGTH OF 8 FT-LB AT $-20^{\circ}F$

- CRITICAL ZONE DEFLECTION LIMITS — HORIZONTAL, 13.5 INCHES
  VERTICAL, 14.5 INCHES

- FALLING OBJECT PROTECTION — 500 LB WEIGHT DROPPED 17 FEET

Figure 3 - SAE Design Criteria

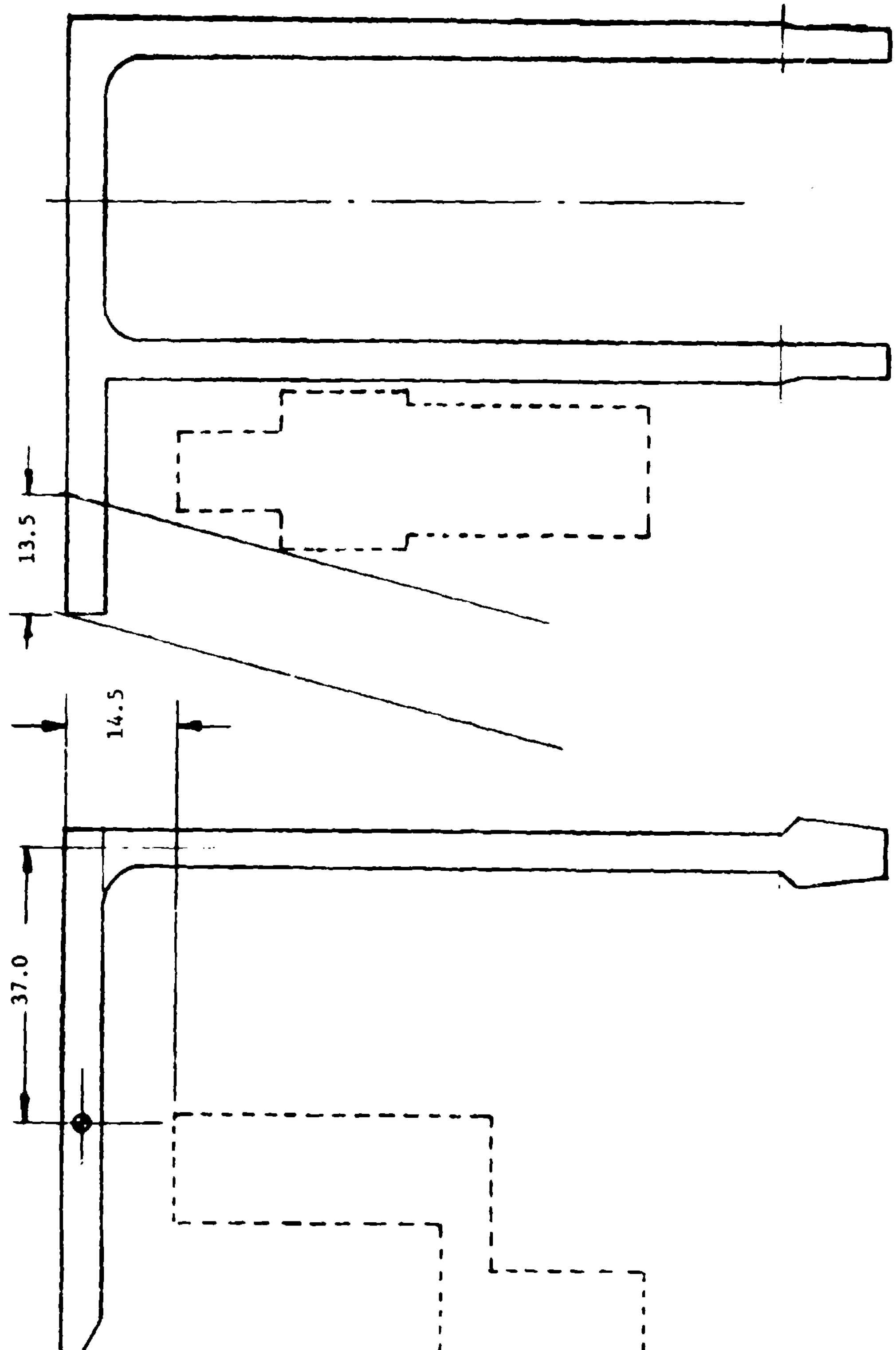


Figure 4 - Critical Zone Criteria

and computing the allowable travel at the load application point.

The minimum performance criteria for the falling object protective structure is specified in SAE Recommended Practice J231. The important requirements are that a 500-lb weight with a 8.0-inch diameter dropped 17 feet over the critical zone does not permit the weight or ROPS structure to intrude into the critical zone.

5.1.1.2 Preliminary Design Feasibility Studies

The results of preliminary design studies showed that retrofitting a ROPS to the 6000-lb forklift was feasible. The 6K Forklift was examined during fabrication at the manufacturer's facility for available space and possible interferences with ROPS envelope by wheels or other operating parts of the Forklift Truck. This investigation indicated that several locations for ROPS installation were available behind the operator, but severe interference problems were encountered in areas ahead of the operator. Therefore, a two post concept seemed to be more feasible than a four-post.

Two positions were found to be favorable. The best choice appeared to be aft of the hydraulic reservoir. This location for ROPS installation offered advantages of accessability, existing chassis rigidity due to axle mount structure and low overall cost because of minimal vehicle modification. However, the extensive overhang due to the distance to the critical zone resulted in a heavier ROPS with greater loads induced into the chassis. The heavier ROPS was needed to meet the minimum side load requirements and to provide sufficient rigidity to achieve the required energy level. Also, the overturning moment during vertical loading produced higher bending stresses in the posts.

The second choice for locating the vertical posts was forward of the hydraulic reservoir. Advantages of this attachment location were a lighter ROPS with less overhang and lower loads to be transferred into the chassis structure. With this concept extensive modifications to the vehicle would be required. These modifications would consist of relocation of the hydraulic reservoir and associated hydraulic lines, and redesign of the steering mechanism. Another disadvantage of this location was inadequate clearance for the ROPS attachment structure.

Brief preliminary analyses were made of the two-post designs attached at these locations. Steel tubing 4 x 4 x 1/2 was adequate for the forward mount; while 5 x 5 x 3/8 was required for the posts attached behind the hydraulic reservoir. Structural design of the ROPS hardware was complicated by the SAE requirements which specify that a minimum amount of energy (area under the force-deflection curve) must be achieved while maintaining a minimum side load. In addition, the structure cannot deflect into the defined "critical zone". Therefore, the structure was carefully sized to reach the minimum side load and be flexible enough to absorb the required energy without intruding into the critical zone.

Although choice of the two-post design concept was dictated primarily by space availability, other advantages are also realized over the four-post design. These include better forward visibility, lower cost and weight, and a nestability capability for shipping with the ROPS detached from the vehicle. Potential advantages of a four-post design would be greater industry experience and correlation to SAE requirements, and a more stable configuration for fore-aft and vertical loads.

5.1.1.3 Design (Development Unit)

The final design configuration of the Development Unit is shown in the following figures:

- o Drawing 299025, ROPS Assembly on Frame, 6K Forklift-Layout, Figure 5
- o Drawing 299026, Roll Over Protective Structure, 6K Forklift, Figure 6
- o Drawing 299027, ROPS Mounting Bracket and Axle Mount Support Cap, 6K Forklift, Figure 7
- o Drawing 299030, Frame Reinforcement Details, 6K Forklift, Figure 8.

Design of the development unit was completed while meeting the following constraints imposed by USAMERDC:

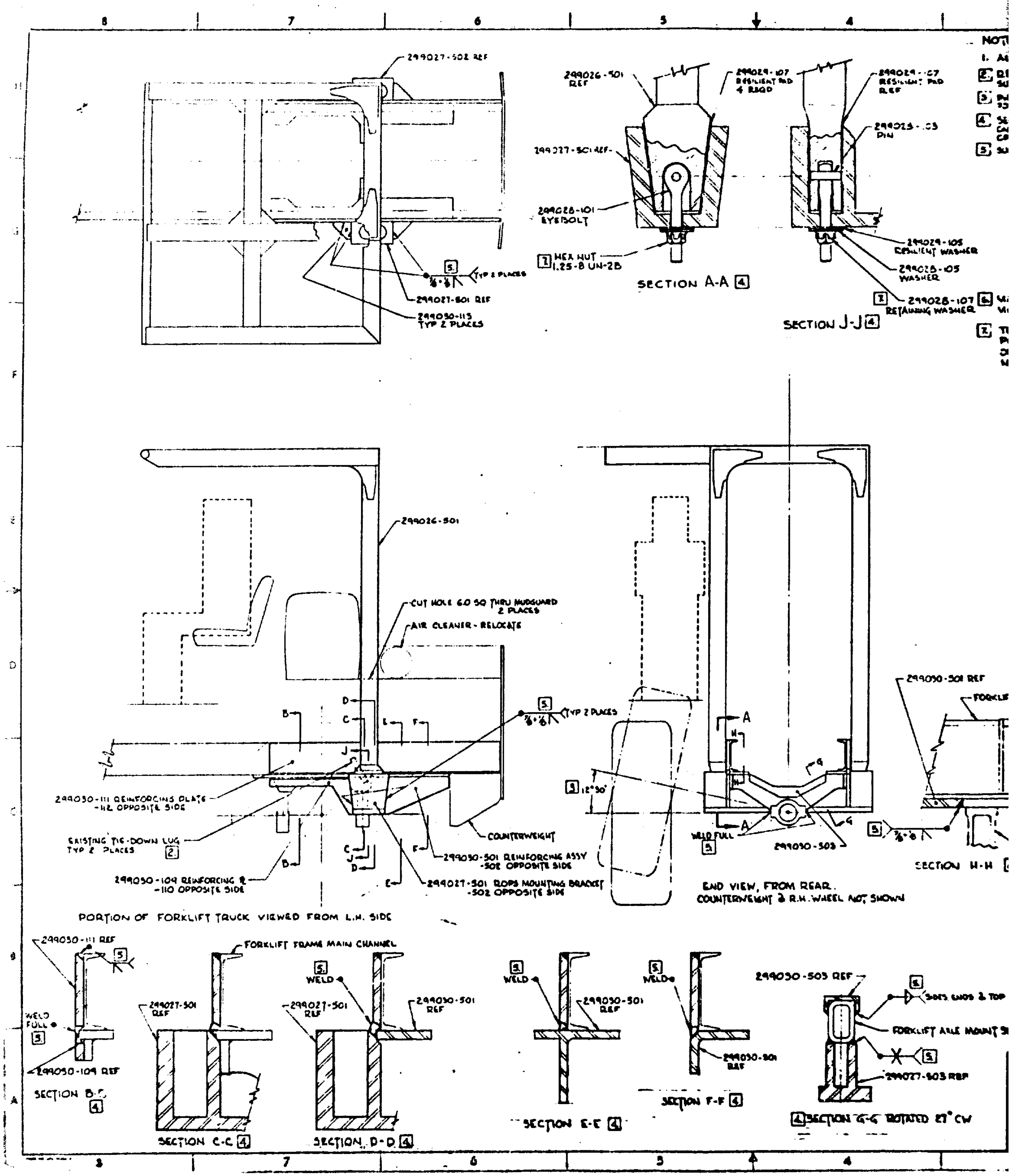
1. The design must meet all applicable SAE criteria.
2. The ROPS must be interchangeable and removable.
3. Upward shift of the vertical center of gravity should be minimized.
4. Obstructions to upward visibility should be minimized.

In addition, the design was guided by the list of groundrules summarized in Figure 9.

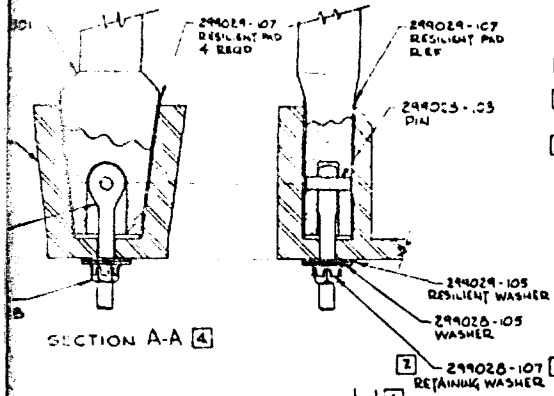
The ROPS, Drawing 299026, is supported by two vertical posts and has wire mesh to provide overhead protection for falling objects.

The top of the ROPS canopy is fabricated primarily from square tubing. The major support members are 5 x 5 x .375 inch square tubes. To achieve a low center of gravity, beams which are not heavily loaded are 5 x 5 x .25 inch square tubes. The front beam is 2.50 inch daimeter tubing to permit good visibility of the fork load when in an "up" position. Lifting brackets welded to each side of the roof are designed to carry three times the ROPS weight. As a safety precaution, the welds are sized to fail under the combined weight of the ROPS and vehicle.

A wire mesh is provided in the region directly above the operator to permit good upward visibility at the same time as falling object protection (FOPS). The mesh is fabricated from 2 x 2 x 0.50 diameter 8620 hot-rolled steel wire. The remainder of the ROPS roof is covered with 0.50 inch steel bar stock spaced at 5.0 to 6.0 inches. This spacing is similar to the original rock guard and gives adequate protection of the equipment from objects falling from the forklift load.



8
7
6
5
4
NOTES
299027-502 REF
TYP 2 PLACES
299027-501 REF
299030-115 TYP 2 PLACES
299026-501 REF
299029-107 RESILIENT PAD 4 REQD
299027-501 REF
299028-101 EYEBOLT
HEX NUT 1.25-8 UN-2B
SECTION A-A
299029-107 RESILIENT PAD REF
299025-103 PIN
299029-105 RESILIENT WASHER
299028-105 WASHER
299028-107 RETAINING WASHER
SECTION J-J
299026-501
CUT HOLE 6.0 SQ THRU MUDGUARD 2 PLACES
AIR CLEANER - RELOCATE
TYP 2 PLACES
299030-111 REINFORCING PLATE -112 OPPOSITE SIDE
EXISTING TIE-DOWN LUG TYP 2 PLACES
299030-109 REINFORCING -110 OPPOSITE SIDE
COUNTERWEIGHT
299030-501 REINFORCING ASSY -502 OPPOSITE SIDE
299027-501 ROPS MOUNTING BRACKET -502 OPPOSITE SIDE
PORTION OF FORKLIFT TRUCK VIEWED FROM L.H. SIDE
12°30'
WELD FULL
299030-503
END VIEW, FROM REAR. COUNTERWEIGHT & R.H. WHEEL NOT SHOWN
299030-501 REF
SECTION H-H
299030-111 REF
WELD FULL
299030-109 REF
SECTION B-B
FORKLIFT FRAME MAIN CHANNEL
299027-501 REF
SECTION C-C
WELD
299027-501 REF
299030-501 REF
SECTION D-D
WELD
299030-501 REF
SECTION E-E
WELD
299030-501 REF
SECTION F-F
299030-503 REF
SIDES ENDS & TOP
FORKLIFT AXLE MOUNT
299027-503 REF
SECTION G-G ROTATED 27° CW

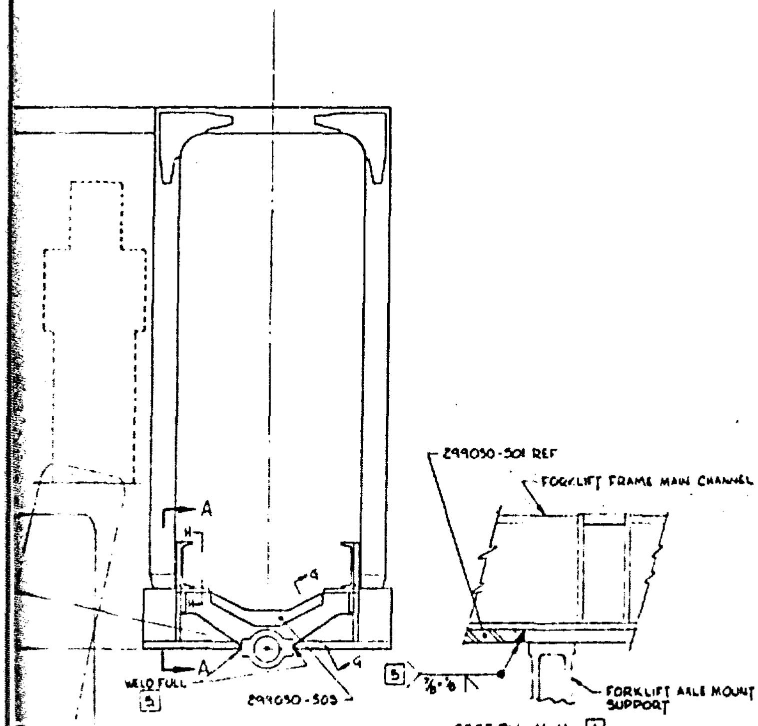


SECTION A-A 4

SECTION J-J 4

NOTES:

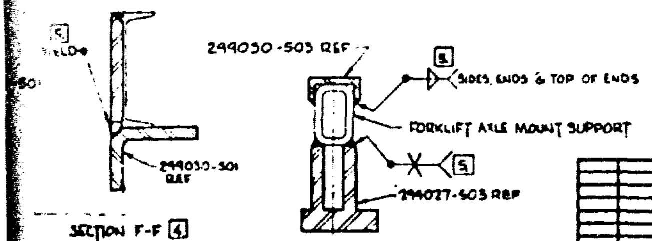
1. ALL WELDING PER DPSF100.
2. REMOVE TIE-DOWN LUGS AND GRIND FRAME SURFACE SMOOTH.
3. PHANTOMED WHEEL SHOWN IN EXTREME OSCILLATING POSITION
4. SECTIONS SHOWN ARE ¼ SCALE AND ARE REPEATED ON OPPOSITE SIDE OF FORKLIFT WITH APPROPRIATE OPPOSITE SIDE PARTS. ROPS OMITTED FOR CLARITY
5. SUGGESTED WELD SEQUENCE
   a) WELD 299030-503 TO AXLE MOUNT SUPPORT,
   b) WELD 299030-501/502 TO FRAME MAIN CHANNELS FILLET WIDTH ½ MAX WELD END TO FRAME MEMBER PER VIEW H-H.
   c) WELD 299027-501/502 TO FRAME MAIN CHANNELS AND TO AXLE MOUNT SUPPORT.
   d) WELD 299030-109/110 TO FRAME MEMBERS
   e) WELD 299030-104 & -501 TO 299027 AND REPEAT ON OPPOSITE SIDE WITH APPROPRIATE OPPOSITE SIDE PARTS.
   f) WELD 299030-111/112 TO FRAME MAIN CHANNELS FILL LOWER WELDS FLUSH.
   g) WELD 299030-113 (2 PIECES) IN PLACE ON 2 SIDES OF FRAME
6. MATERIAL SPEC: ASTM A-194 GRADE 7, WITH MIN ULTIMATE TENSILE STRENGTH OF 160000 PSI.
7. TORQUE NUTS TO 500 TO 550 FOOT POUNDS WET. FOLD AT LEAST 3 TABS OF RETAINING WASHER TO ENGAGE ALTERNATE NUT FLATS.



SECTION H-H 4

END VIEW, FROM REAR,
COUNTERWEIGHT & R.H. WHEEL NOT SHOWN

✓			WELDING		DPSF100	
2			HEX NUT-1.25-8 UN-2B	6	6	G6
2		299028-107	WASHER-RETAINING			G4
2		299028-105	WASHER			G4
2		299028-103	PIN			H4
2		299030-113	PLATE-REINFORCING			F6
1		299030-112	PLATE-REINFORCING			C8
1		299030-111	PLATE-REINFORCING			C8
1		299030-110	PLATE-REINFORCING			B8
1		299030-104	PLATE-REINFORCING			C8
1		299030-503	ASSY-REINFORCING			C4
1		299030-502	ASSY-REINFORCING			C6
1		299030-501	ASSY-REINFORCING			C6
					299025	
2		299029-105	WASHER-RESILIENT			G4
						H4
4		299029-107	PAD-RESILIENT			H8
2		299028-101	EYEBOLT-ROPS			G6
1		299027-502	ROPS MOUNTING BRACKET			B6
1		299027-501	ROPS MOUNTING BRACKET			B6
1		299026-501	ROLL-OVER PROTECTIVE STRUCT			B6



SECTION F-F 4

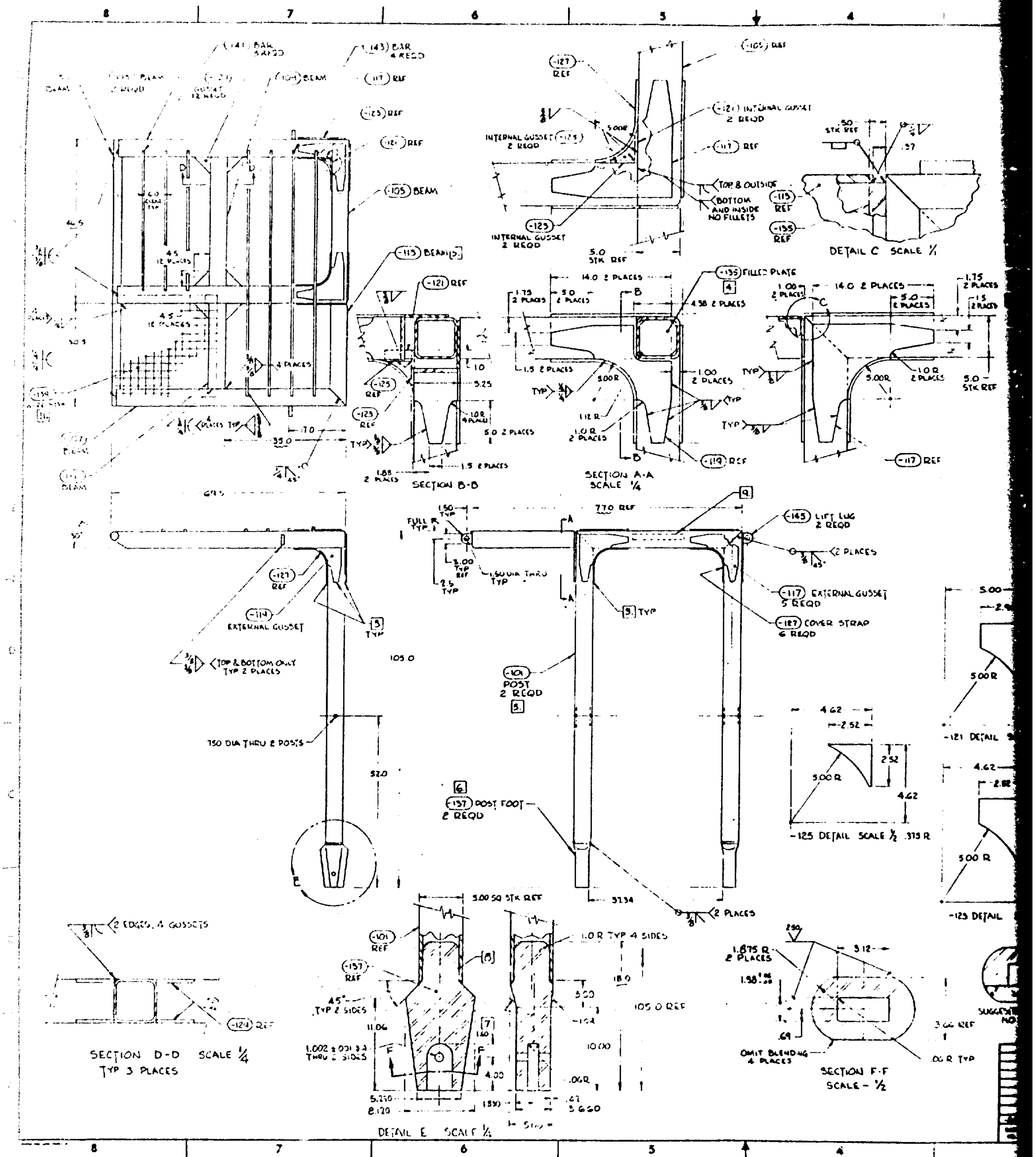
4 SECTION G-G ROTATED 27° CW

ROPS ASSY INSTALLATION
MOUNTED ON GK FORKLIFT

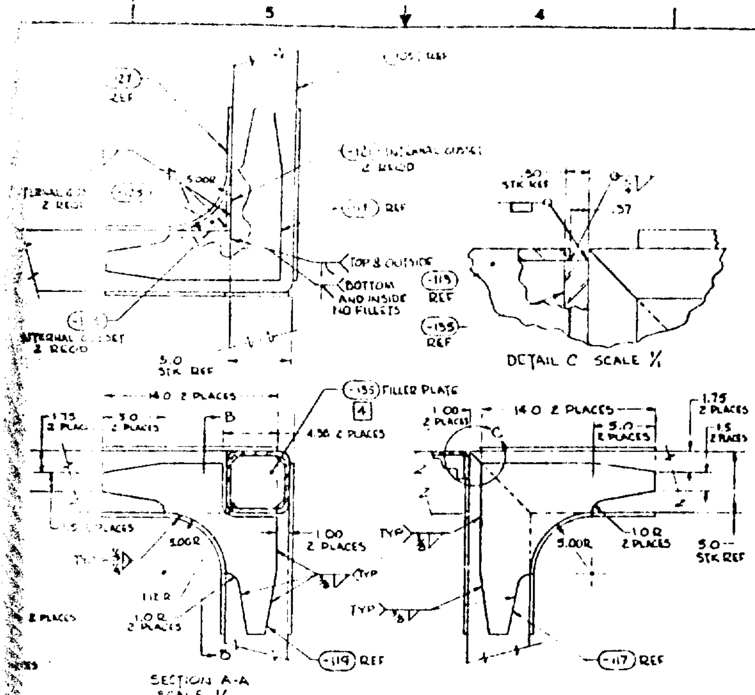
E 06491 299025

FORM 4

MPO 684

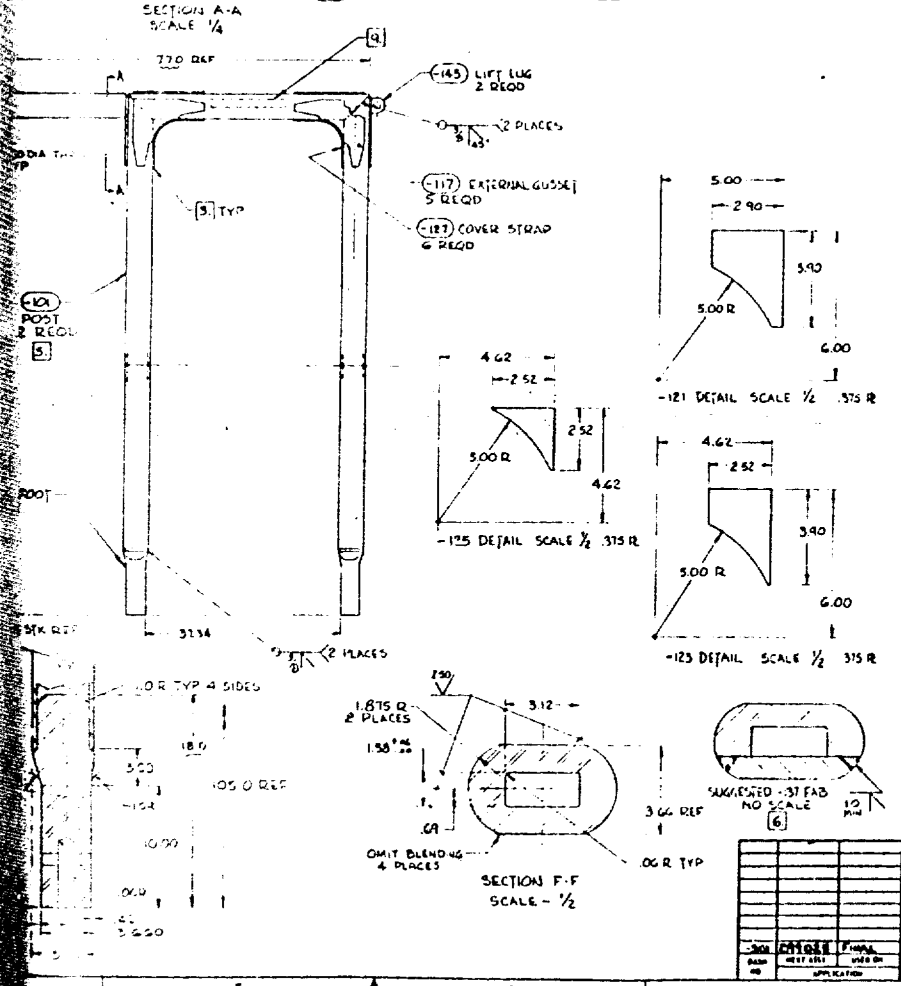


8
7
6
5
4
(-141) BAR 3 REQD
(-143) BAR 4 REQD
(-105) REF
(-127) REF
(-104) BEAM
(-117) REF
(-125) REF
(-121) REF
(-105) BEAM
(-115) BEAM
(-121) REF
INTERNAL GUSSET (-125) 2 REQD
(-121) INTERNAL GUSSET 2 REQD
(-117) REF
TOP & OUTSIDE
BOTTOM AND INSIDE NO FILLETS
(-115) REF
(-135) REF
(-125) INTERNAL GUSSET 2 REQD
5.0 STK REF
.50 STK REF
DETAIL C SCALE ½
4 PLACES
(-135) FILLED PLATE
14.0 2 PLACES
1.75 2 PLACES
5.0 2 PLACES
4.58 2 PLACES
1.5 2 PLACES
1.00 2 PLACES
5.00R
1.0 R 2 PLACES
(-119) REF
SECTION A-A SCALE ¼
(-125) REF
(-123) REF
1.85 2 PLACES
1.5 2 PLACES
5.25
5.0 2 PLACES
SECTION B-B
35.0
17.0
TYP
5.00R
1.0 R 2 PLACES
5.0 STK REF
(-117) REF
69.5
(-127) REF
(-114) EXTERNAL GUSSET
TOP & BOTTOM ONLY TYP 2 PLACES
105.0
.750 DIA THRU 2 POSTS
52.0
E
1.50 TYP
FULL R TYP
3.00 TYP REF
1.500 DIA THRU TYP
2.5 TYP
77.0 REF
(-145) LIFT LUG 2 REQD
2 PLACES
(-117) EXTERNAL GUSSET 5 REQD
(-127) COVER STRAP 6 REQD
(-101) POST 2 REQD
(-157) POST FOOT 2 REQD
57.54
2 PLACES
4.62
2.52
5.00R
-125 DETAIL SCALE ½ .375 R
5.00
5.00R
-121 DETAIL
4.62
5.00 R
-123 DETAIL
2 EDGES, 4 GUSSETS
(-124) REF
SECTION D-D SCALE ¼
TYP 3 PLACES
5.00 SQ STK REF
(-101) REF
(-157) REF
45° TYP 2 SIDES
11.06
1.002 ±.001 3.3 THRU 2 SIDES
5.250
8.120
1.0 R TYP 4 SIDES
18.0
5.00
10.00
4.00
.06R
3.650
105.0 REF
DETAIL E SCALE ¼
1.875 R 2 PLACES
3.12
.69
OMIT BLENDING 4 PLACES
.06 R TYP
SECTION F-F SCALE - ½
3.66 REF



NOTES:

1. ALL WELDING PER DPSF100
2. GRIND FLUSH ALL WELDS COVERED BY GUSSETS.
3. [3] OMIT WELDS ACROSS ENDS OF GUSSETS AND COVER STRAPS
4. [4] TRIM CORNERS OF -135 TO FIT INTO -115
5. [5] SUGGESTED SEQUENCE FOR WELDING -115 TO -101
   a) WELD -135 INTO -115
   b) WELD -135 TO -101 AND FILL FLUSH WITH -115 ALL AROUND.
   c) WHEN WELDING -119 ON, FILL FLUSH ALONG EDGES ADJACENT TO -115.
6. [6] -157 MAY BE FABRICATED BY WELDING & MACHINING WITH PRIOR LPC ENGR APPROVAL
7. [7] SHAPE OF END OF SLOT IS OPTIONAL.
8. [8] MAX CLEARANCE .03, 4 SIDES. CHAM CORNERS OF -157, .76
9. [9] PERMANENT MARK APPROPRIATE PART NO AND SERIAL NO APPROXIMATELY WHERE SHOWN.
10. APPLY 1 COAT INTERNATIONAL NU-PLATE F PRIMER TO -501.
11. [11] WELD -139 STEEL WIRE MESH OVER TOP OF STRUCTURE OVERLAPPING SQUARE MEMBERS BY 2.00 ± .25. OVERLAP FORWARD ROUND TUBE BY 1.25 ± .25. WELD EACH WIRE STRAND WITH DOUBLE .25 FILLET.



QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE
2		-145	LIFT LUG .75 PLATE 3.0 × 3.0	STEEL	EMSD103	C4
4		-143	BAR, ½ SQ × 71.0 LONG	STEEL	EMSD103	H7
3		-141	BAR, ½ SQ × 40.5 LONG	STEEL	EMSD103	H7
✓			WELDING		DPSF100	
AR		NU PLATE F	PRIMER INTERNATIONAL PAINT CO. (INC) 280 S. LINDEN AVE, SOUTH SAN FRANCISCO, CALIF			
1		-139	WIRE MESH, 2×2, .3125 DIA WIRE, M.M. 1246Y 30.0 × 50.0 McMASTER-CARR CO. 9601 JOHN ST. SANTA FE SPRINGS CALIF.			F8
2		-157	POST FOOT [6]	STEEL	EMSD103	C4
1		-135	FILLER PLATE .50 R. 4.5 SQ			G5
						H6
						D8
12		-129	GUSSET-TRIANGULAR .375 R. 4.5 × 4.5			H7
6		-127	COVER STRAP .375 R. 8.25 × 17.5			D4
2		-125	GUSSET-INTERNAL .375 R. 2.1 × 2.1			H6
2		-123	GUSSET-INTERNAL .375 R. 2.7 × 4.1			G6
2		-121	GUSSET-INTERNAL .375 R. 3.1 × 4.1			H5
1		-119	GUSSET-EXTERNAL .375 R. 14.0 × 14.0			D7
5		-117	GUSSET-EXTERNAL .375 R. 14.0 × 14.0		EMSD103	D4
1		-115	BEAM-TUBING-2.5 DIA, .25 WALL, 77.6 LONG		EMSD104	H8
1		-113	BEAM-TUBING-5.0 SQ, .25 WALL, 32.0 LONG		EMSD104	G6
1		[illegible]	BEAM-TUBING-5.0 SQ, .25 WALL, 25.5 LONG			E8
1		-109	BEAM-TUBING-5.0 SQ, .25 WALL, 37.0 LONG			H7
1		-107	BEAM-TUBING-5.0 SQ, .25 WALL, 69.0 LONG			E8
1		-105	BEAM-TUBING-5.0 SQ, .375 WALL, 44.0 LONG			G6
2		-103	BEAM-TUBING-5.0 SQ, .375 WALL, 64.0 LONG			H8
2		-101	POST-TUBING-5.0 SQ, .375 WALL, 95.0 LONG	STEEL	EMSD104	D6

LIST OF MATERIALS OR PARTS LIST

299026

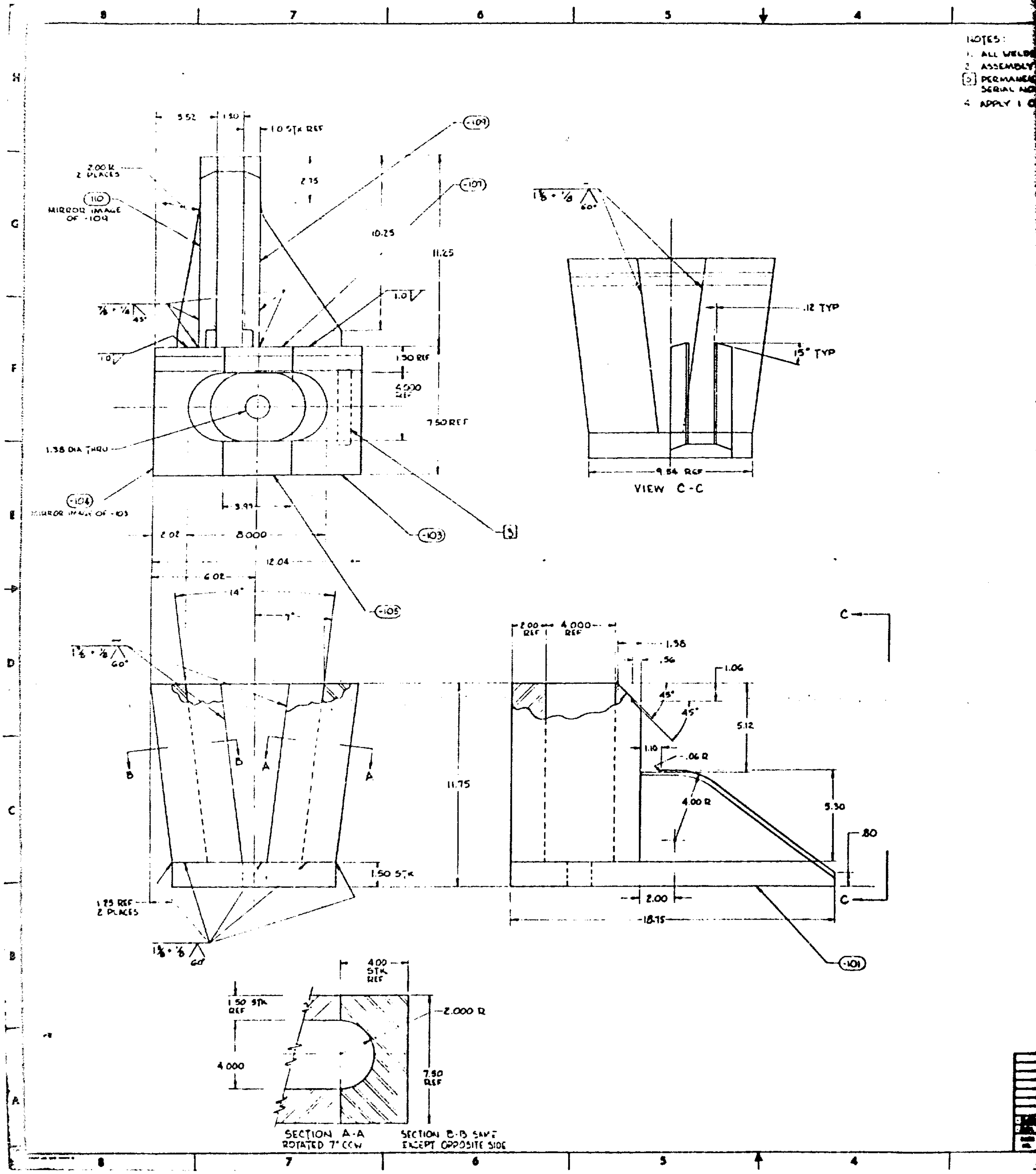
LOCKHEED PROPULSION COMPANY

ROLL OVER PROTECTIVE STRUCTURE GK FORKLIFT

SIZE E | CODE IDENT NO 06491 | DRAWING NO 299026

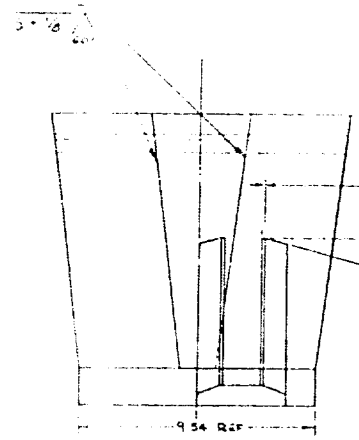
SCALE 1/2 | SHEET 1

FORM 4 | MPO 654 | 159A-1003

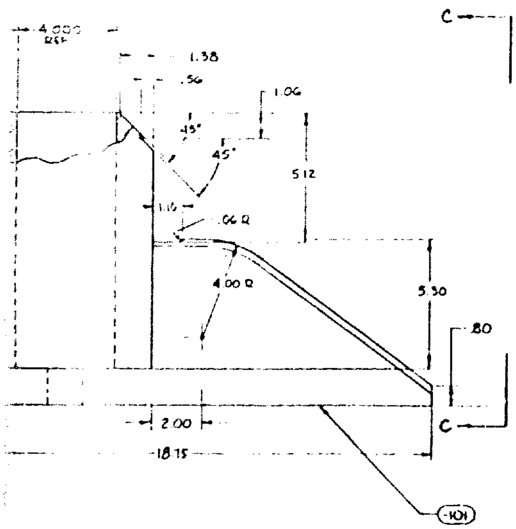

NOTES:
1. ALL WELD
2. ASSEMBLY
[5] PERMANEN SERIAL NO
4. APPLY 1 C
VIEW C-C
SECTION A-A ROTATED 7° CCW
SECTION B-B SAME EXCEPT OPPOSITE SIDE
MIRROR IMAGE OF -109
MIRROR IMAGE OF -103
1.38 DIA THRU
9.54 REF
18.75
11.75
11.25
10.25
7.50 REF
12.04
8.000
4.000
2.000 R
4.00 R
.12 TYP
15° TYP
14°
7°
-101
-103
-104
-105
-107
-109
-110

NOTES:

1. ALL WELDS PER DPSF100.
2. ASSEMBLY -502 IS A MIRROR IMAGE OF -501 (SHOWN)
3. [5] PERMANENTLY MARK APPROPRIA_ PART NO. AND SERIAL NO. APPROXIMATELY WHERE SHOWN.
4. APPLY 1 COAT OF INTERNATIONAL NU PLATE F PRIMER.



VIEW C-C



AR	AR		NU PLATE F	PRIMER INTERNATIONAL PAINT CO (CALIF) 220 S. LINDEN AVE, SOUTH SAN FRANCISCO CAL		
✓	✓			WELDING		DPSF100
						299027
1	1		-110	PLATE-1.0×5.5×10.5	STEEL	EMSD105
1	1		-109	PLATE-1.0×5.5×10.5		
1	1		-107	PLATE-1.50×4.00×11.0		
1	1		-105	PLATE-2.0×4.00×11.0		
1	1		-104	BAR-4.00×7.50×11.0		
1	1		-103	BAR-4.00×7.50×11.0		
1	1		-101	PLATE-1.50×10.0×19.0	STEEL	EMSD105
-502	-501					

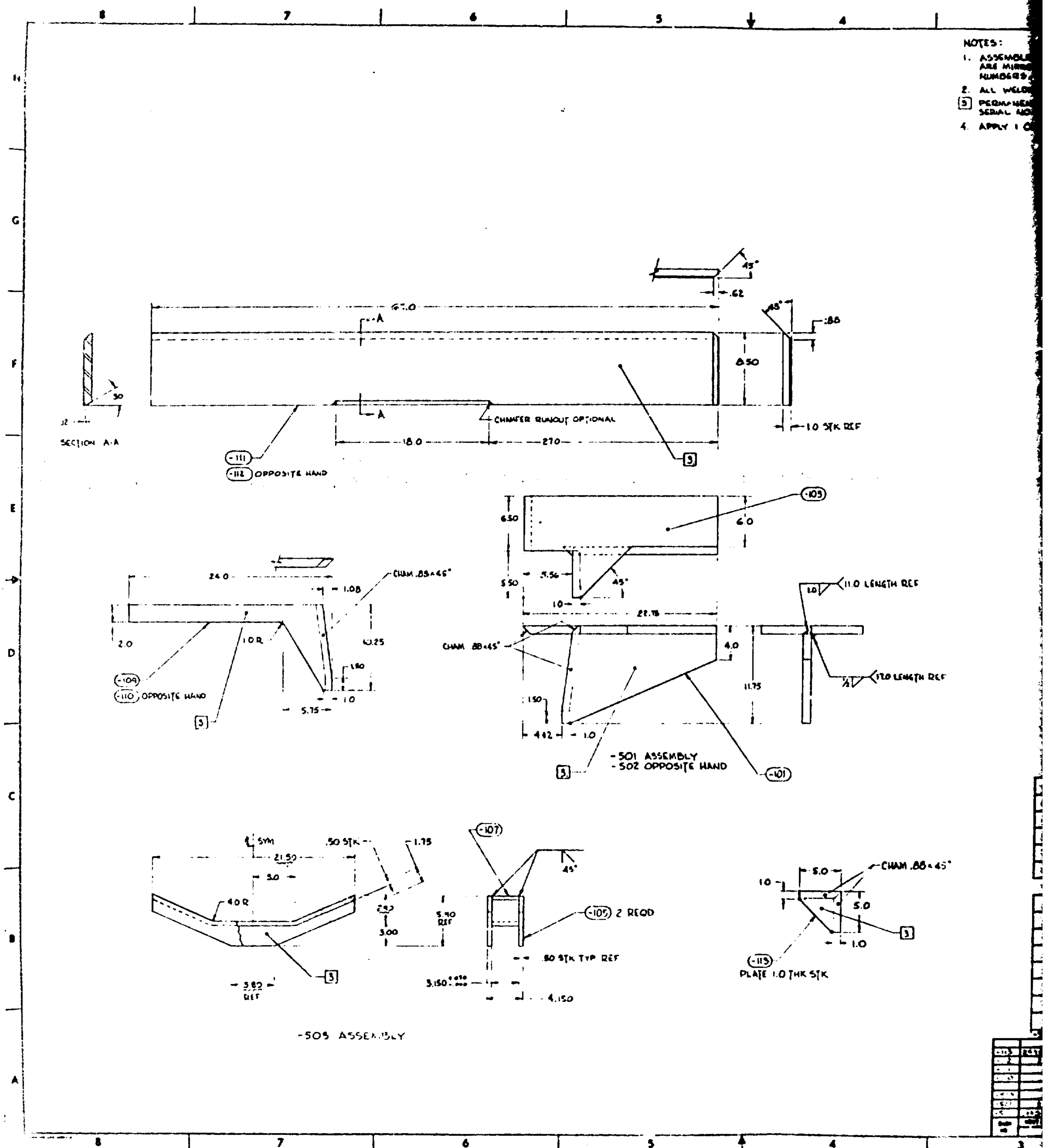
ROPS MOUNTING BRACKET
6K FORKLIFT

E 06491 299027

FORM 4

MPO 694

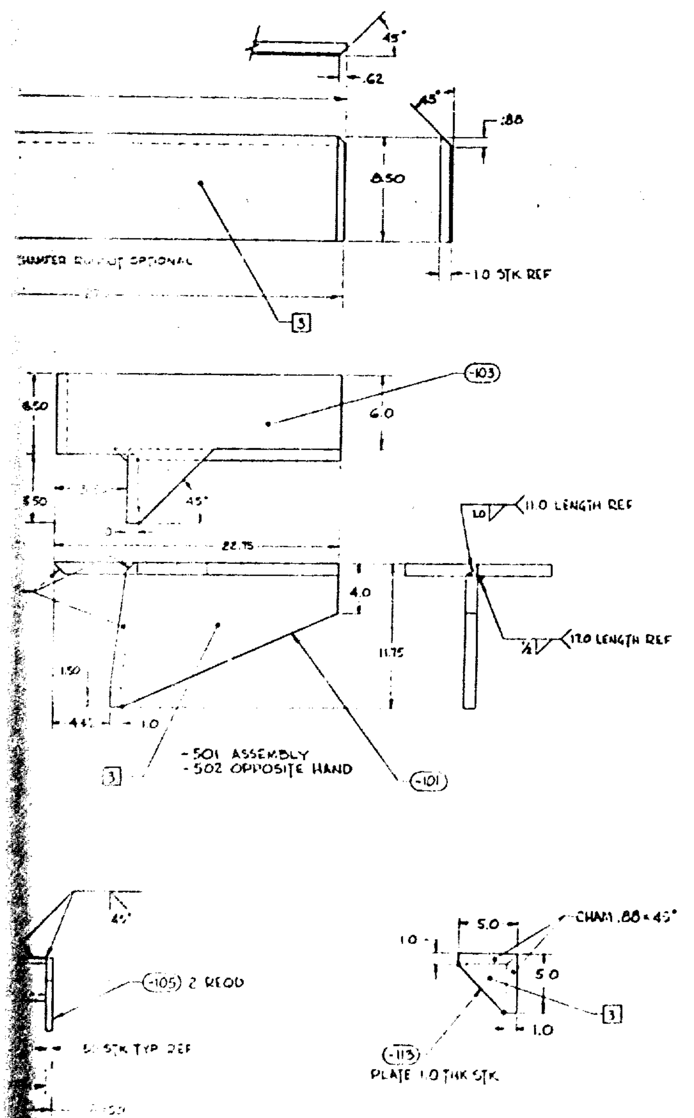
SBA 1005



NOTES:
1. ASSEMBL... ARE MIRR... NUMBERS...
2. ALL WELD...
3 PERMANEN... SERIAL NO...
4. APPLY 1 C...
SECTION A-A
-111
-112 OPPOSITE HAND
CHAMFER RUNOUT OPTIONAL
1.0 STK REF
-109
-109
-110 OPPOSITE HAND
CHAM .88×45°
CHAM .88×45°
11.0 LENGTH REF
12.0 LENGTH REF
-501 ASSEMBLY
-502 OPPOSITE HAND
-101
-107
-105 2 REQD
.50 STK TYP REF
-113
PLATE 1.0 THK STK
CHAM .88×45°
-505 ASSEMBLY

NOTES:

1. ASSEMBLIES AND PARTS IDENTIFIED BY EVEN NUMBERS ARE MIRROR IMAGES OF THOSE WITH PRECEDING ODD NUMBERS.
2. ALL WELDING PER DPSF100.
3. PERMANENT MARK APPROPRIATE PART NO. AND SERIAL NO. IN APPROXIMATE LOCATION SHOWN.
4. APPLY 1 COAT OF INTERNATIONAL NU PLATE F PRIMER.



				CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			1		-113	PLATE - 1.0 × 5.0 × 5.0	STEEL	EMSD105
AR	AR	AR	AR		NU PLATE F	PRIMER - INTERNATIONAL PAINT CO. (CALIF) 220 SO. LINDEN AVE., SOUTH SAN FRANCISCO CALIF		
✓	✓	✓	✓			WELDING		DPSF100
			1		-112	PLATE - 1.0 × 8.50 × 67.0	STEEL	EMSD105
			1		-111	PLATE - 1.0 × 8.50 × 67.0		
			1		-110	PLATE - 1.0 × 10.25 × 24.0		
			1		-109	PLATE - 1.0 × 10.25 × 24.0		
1					-107	PLATE - .50 × 3.15 × 25.50		
2					-105	PLATE - .50 × 6.00 × 21.50		
	1				-104	PLATE - 1.0 × 12.00 × 22.75		
		1			-103	PLATE - 1.0 × 12.00 × 22.75		
	1				-102	PLATE - 1.0 × 6.75 × 18.50		
		1			-101	PLATE - 1.0 × 10.75 × 18.50	STEEL	EMSD105
-503	502	501		QTY REQD				

LIST OF MATERIALS OR PARTS LIST

LOCKHEED PROPULSION COMPANY

FRAME REINFORCEMENT DETAILS GN FORKLIFT

E 06491 299030

299030

MPO 694

155A-1005

17

- MAKE EXTENSIVE USE OF "CAT-CLARK" ROPS TEST DATA
- CONSIDER ACTUAL ROLL-OVER INFLUENCE ON DESIGN
- DESIGN MUST PROVIDE ROLL-OVER PROTECTION WITH SIDE LOAD APPLIED AT EITHER SIDE OF ROOF AT ANY FORE/AFT LOCATION
- ROPS TO BE INTERCHANGEABLE-TOLERANCE CONTROL REQUIRED
- USE SIMPLE AND PROVEN DESIGN/FABRICATION TECHNIQUES
- USE LPC AND INDUSTRY EXPERIENCE WHERE POSSIBLE
- ABSORB ENERGY IN SIMPLE, ANALYTICALLY PREDICTABLE AREAS OF THE STRUCTURE AND AVOID LOCAL BUCKLING FAILURES
- MINIMIZE STIFFNESS WHILE STAYING WITHIN LOAD CONSTRAINTS TO PRECLUDE TRACTOR FAILURE
- MINIMIZE COST
- MINIMIZE VEHICLE MODIFICATIONS
- LIMIT OPERATOR VISIBILITY RESTRICTIONS
- MINIMIZE TRACTOR PERFORMANCE DEGRADATION
- LIMIT NOISE AND VIBRATION INDUCED BY ROPS
- PROVIDE FOR NESTING CAPABILITY DURING SHIPPING IF POSSIBLE
- MINIMIZE INTERFERENCE WITH MAINTENANCE OPERATION

Figure 9 - Design Groundrules

The roof is supported by two vertical posts fabricated with 5.0 inch square tubing with a 0.375 inch wall thickness. The posts are spaced 37.33 inches apart to straddle the main support channels of the forklift chassis. The junction of these members with the roof has reinforcements in all planes to achieve good load and moment transfer.

The corner gussets are built up with 0.375 inch thick plates. They are welded together and to the square tubes. This type of corner reinforcement has advantages of wide industry usage with proven structural capability and excellent load transfer. Although this configuration requires many parts and considerable welding, it does not require special forming or bending techniques during fabrication. The width of the gusset plates are tapered to assure a gradual transition of load and a weld joint removed from the area of maximum bending stress in the tube. A curved plate is welded to the free edge of the gusset to preclude local buckling failures. A threaded bar spanning the two posts is provided to facilitate lateral adjustment of the ROPS during installation.

The lower end of the ROPS vertical support members are attached with a foot-socket arrangement. Threaded eye-bolts engage the feet into the sockets and permit easy removal of the ROPS. The steel post feet extend 5.0 inches into the tubes and are attached with a weld joint around the entire tube end. The portion of the foot which extends into the socket is tapered to achieve rigid fixity and easy installation. The eye-bolt is held in the foot with a 1.0 inch diameter pin which is retained by the side walls of the socket after installation of the ROPS. Noise and vibration isolation is obtained by placing sheets of "Fabreeka", a rubber-cotton composite material, between the sidewalls of the socket and under the nut.

The sockets are fabricated with an assembly of plates joined with penetration welds. The receptacles for the feet are curved to distribute the bearing loads in a manner which will reduce the stresses in the welds. Loads are transmitted from the sockets to the axle housing through "U" shaped reinforcements which are welded to the sockets and axle housing. The top of the axle housing is reinforced with another "U" shaped member.

The basic frame members of the forklift chassis are reinforced to distribute the loads incurred during rollover. Two 1.0 inch plates extending 67.0 inches along the frame channels provide the primary structural support. In addition, plates are provided below the frame channels and attached to the forward and aft faces of the sockets to give further chassis reinforcement and load distribution.

5.1.1.4 Material and Weld Requirements

During the design phase, specifications were written to establish the requirements for the materials and welding to be used in the roll-over protective structures. These specifications meet the requirements of the applicable SAE recommended practice and are consistent with the design criteria.

The material requirements for the high strength carbon steel are given in Material Specification EMSD103, Appendix 6.1.1 and the carbon steel tubing requirements are specified in Material Specification EMSD104, Appendix 6.1.2. All of the steel used in the design of the ROPS and chassis reinforcements meets the SAE impact strength requirement of 8 ft-lb at -20^{o}F with a 10 mm x 10 mm test specimen.

The material properties for the plate and tubing members used in the design and analysis are presented in Figures 10 and 11, respectively. These levels can be easily achieved with "ROPS charpy steel" commonly used throughout the industry. However, the tubing yield strength of 50,000 psi is above the level used commonly. This requirement is necessary to withstand the vertical loading with the two post design. ROPS fabricators have indicated that this strength level will be easily attainable during production.

The FOPS mesh is fabricated with 8620 hot rolled steel. The material passed the 8 ft-lb at -20^{o}F Charpy Vee Notch Impact Test requirement with a full size (10 mm x 10 mm) specimen.

The welding requirements are given in Process Specification DPSF100, Appendix 6.1.3. This specification details the standards for qualifying welders, lists filler metals which will meet impact requirements, specifies acceptable equipment and outlines the quality assurance standards.

5.1.2 Structural Analysis

5.1.2.1 Analysis Approach

The method used for structural analysis was to determine the elastic curve of the ROPS, support structure, and vehicle by computer program and conventional analysis and to determine the ROPS ultimate capability with the non-linear computer program. Then, using structural internal loads for maximum ROPS side load and one 'g' vertical load, a detail structural analysis was performed on the ROPS, support structure, and vehicle. Factors of safety for the structure were obtained by comparing material yield strength to stresses obtained from the above loading conditions.

An assumption made to simplify the computer model was the longitudinal vehicle frame does not have pitch rotation. This is completely true during the side load test because both sides of the frame are tied down at two locations. This assumption is felt to be accurate during actual rollover, also because numerous vehicle cross ties, axles, and engine prevent relative frame rotation. An additional modeling assumption used is that the ROPS foot is completely fixed in the socket. This assumption is true for large ROPS deflections and produces accurate results for ROPS ultimate capability. However, as shown by Figure 12, in the small deflection range considerable discrepancy is obtained. This is due to the ROPS feet rotating in the socket while absorbing socket clearance. Therefore, the elastic curve prediction was based on test data obtained from the caterpillar ROPS bedplate test.

* PLATE

o	MATERIAL	ASTM-A-516 STEEL
o	ULTIMATE TENSILE STRENGTH, F_{tu}	70,000 to 90,000 PSI
o	TENSILE YIELD STRENGTH, F_{ty}	38,000 PSI
o	SHEAR STRENGTH, F_{su}	44,000 PSI
o	ULTIMATE BEARING STRENGTH, F_{bru}	115,000 PSI
o	MODULUS OF ELASTICITY, E	29.0×10^6 PSI
o	MODULUS OF RIGIDITY, G	11.2×10^6 PSI
o	POISSONS'S RATIO	0.30
o	CHARPY V-NOTCH IMPACT STRENGTH AT $-20^{\circ}F$	8 FT-LB
o	DENSITY, W	0.283 LBS/IN^3

* LPC SPECIFICATION NO. EMSD104

Figure 10, ROPS Plate Material Properties

* ROPS TUBULAR MEMBERS

o	MATERIAL	ASTM-A-500 STEEL
o	ULTIMATE TENSILE STRENGTH, F_{tu}	60,000 to 80,000 PSI
o	TENSILE YIELD STRENGTH, F_{ty}	50,000 PSI
o	COMPRESSIVE YIELD STRENGTH, F_{cy}	50,000 PSI
o	SHEAR STRENGTH, F_{su}	38,000 PSI
o	ULTIMATE BEARING STRENGTH, F_{bru}	98,000 PSI
o	MODULUS OF ELASTICITY, E	29.0×10^6 PSI
o	MODULUS OF RIGIDITY, G	11.2×10^6 PSI
o	POISSON'S RATIO, ν	0.30
o	CHARPY V-NOTCH IMPACT STRENGTH AT $-20^{\circ}F$	8 FT-LB
o	DENSITY, W	0.283 LBS/IN^3

* LPC Specification No. EMSD104

Figure 11 - ROPS Tube Material Properties

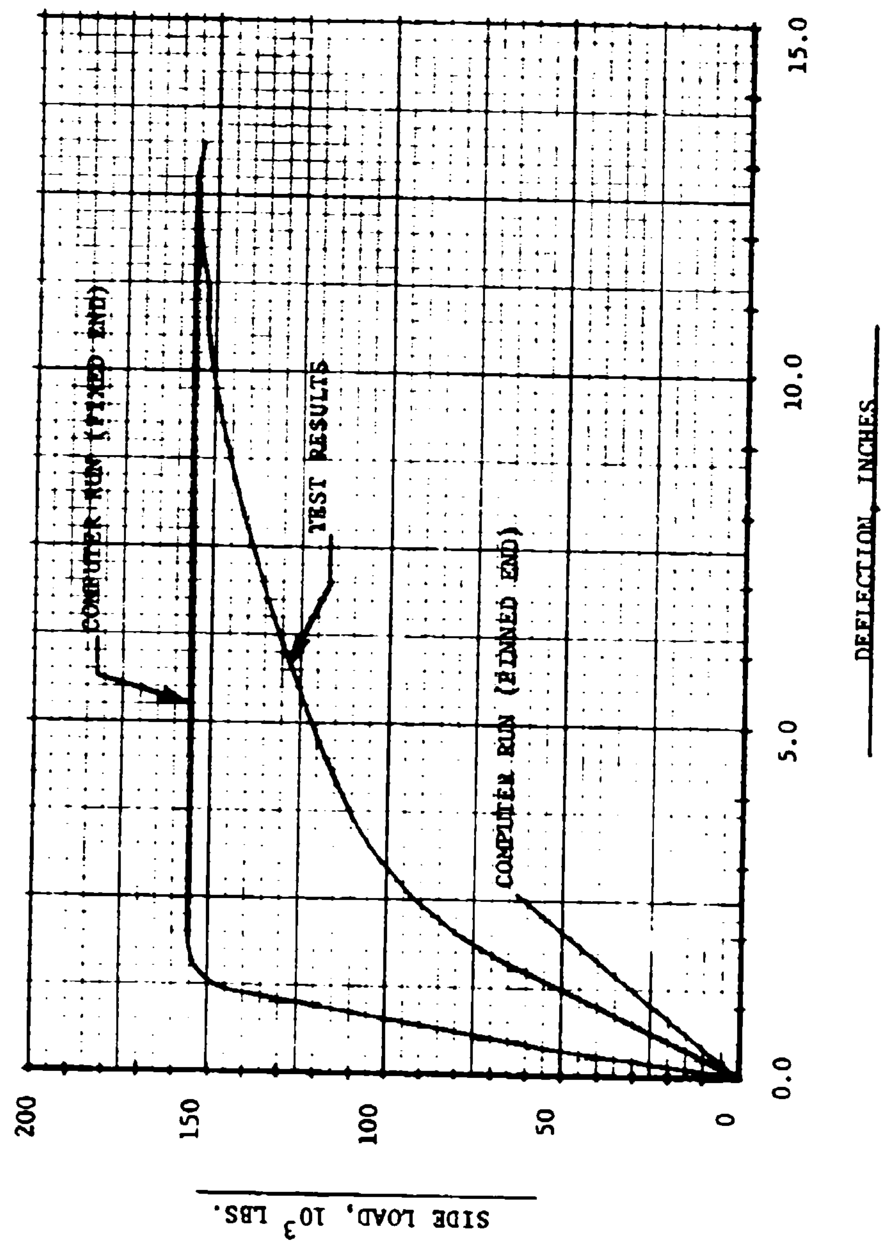


Figure 12 - Comparison of Caterpillar ROPS Bedplate Test and Computer Analysis Results

5.1.2.2 Analysis Results

The predicted ROPS side load vs. deflection curve is shown in Figure 13. The elastic and elastic-plastic transition section of the curve is based on test results from the caterpillar ROPS bedplate test and the ultimate capability value of 28,000 lbs is based on the non-linear computer program output. Figure 13 also shows the results from the non-linear program for a partially pinned (fixed for foot torsion) and fully fixed lower end ROPS. The pinned end curve cannot be used for prediction because its elastic slope is less than expected and, it develops about one-half of the ultimate capability. The fixed end curve cannot be totally used because its small deflection stiffness is excessive. These curves point out a non-linear fixity mechanism has to be developed for a computer model of ROPS with sockets to accurately predict load vs. deflection in a single run. A non-linear fixity mechanism is presently being developed to be incorporated in the ROPS computer procedure.

The computer predicted ROPS vertical load vs. deflection curve is shown in Figure 14. The effect of socket clearance was not included at this time.

A plot of the ROPS model is shown in Figure 15. This plot is a model of the pinned lower end ROPS; therefore, no frame influence is necessary. The computer program includes this model plotting capability to help check for model geometry errors and to provide a plot of the model deflected shape.

The structural analysis of the unit is given in Section 6.2 of the Appendix and a summary of the results is shown in Tables 1, 2 and 3. Table 1 is a summary of the ROPS factors of safety. Due to side load, P_1, local buckling tends to occur at the point of load application. Location 1 is a check of this condition. Since upward visibility is required through this ROPS, roof panels cannot be used. As a result, side load applied forward of the ROPS vertical members have to be transferred by the roof members in bending. This bending causes excessive stresses on the roof mid joints requiring gussets to be added to the joints. Points 2 and 3 are a check of these gussets for the member bending moments. Point 4 is a check for foot bending stresses. Foot bending stresses were compared with ultimate bending stress as foot yielding was permitted. Location 5 is a check of ROPS tube bending stress due to the vertical load, P_2. It is necessary to compare location 5 stress to an allowable yield stress as the roof deflection may become excessive and enter the critical zone at ultimate bending stress.

Table 2 is a summary of the frame stresses due to maximum ROPS side load. Location 1 is a check of weld tension stress due to a right hand side load. Due to a right hand side load, $-P_y$ puts a tension load on 1 and a couple due to $-M_x$ at the top and bottom of the socket puts a tension load on 1. Locations 2 and 3 are a socket tension and shear check due to a right hand side load. The weld tension load at location 1 loads the frame one inch horizontal plate. This load has to be transferred as a shear force down to the axle casting through location 4 weld. Location 4 is a weld shear check for this loading. Location 5 is a weld shear check between the socket vertical structure and bottom plate. The welded axle and reinforcement reacts M_x in bending. This bending causes a weld tension stress at 6 for a right hand side load. Location 6 is a check of this tension stress.

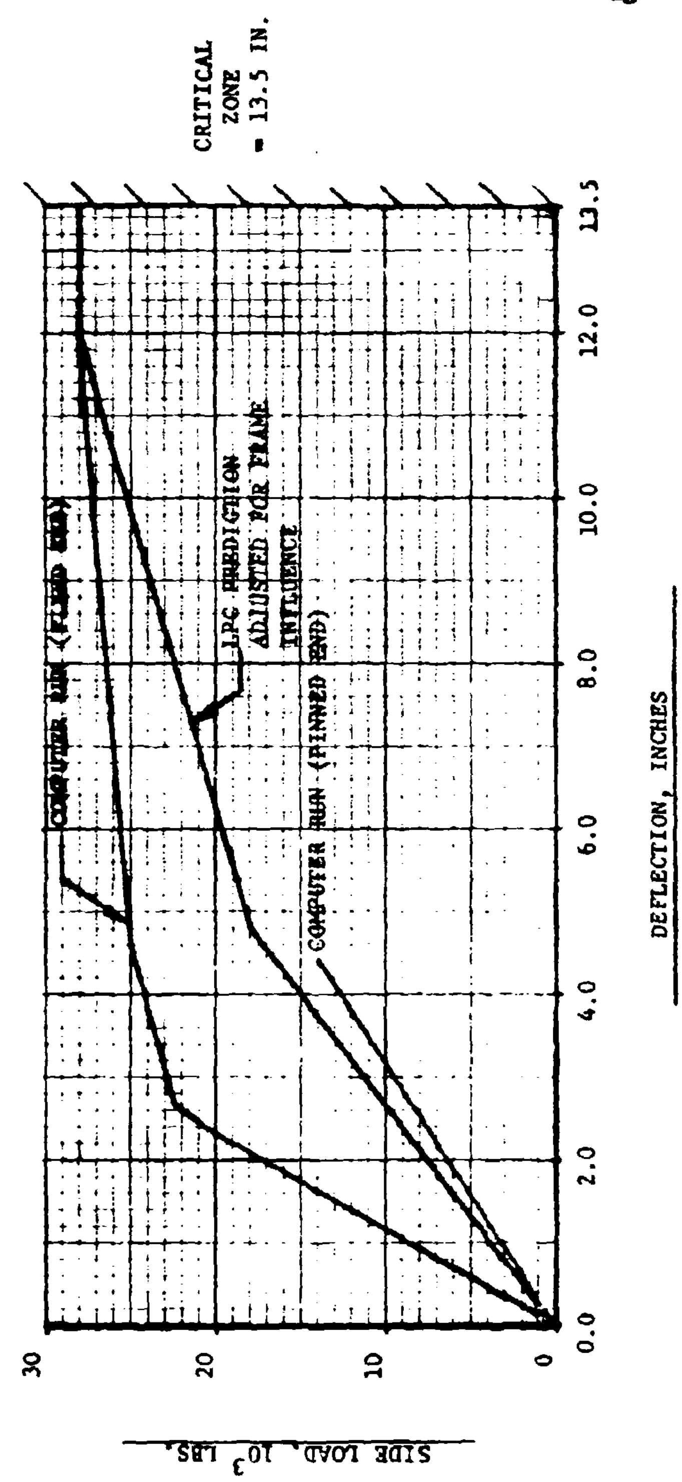


Figure 13 - Predicted ROPS Side Load Deflection

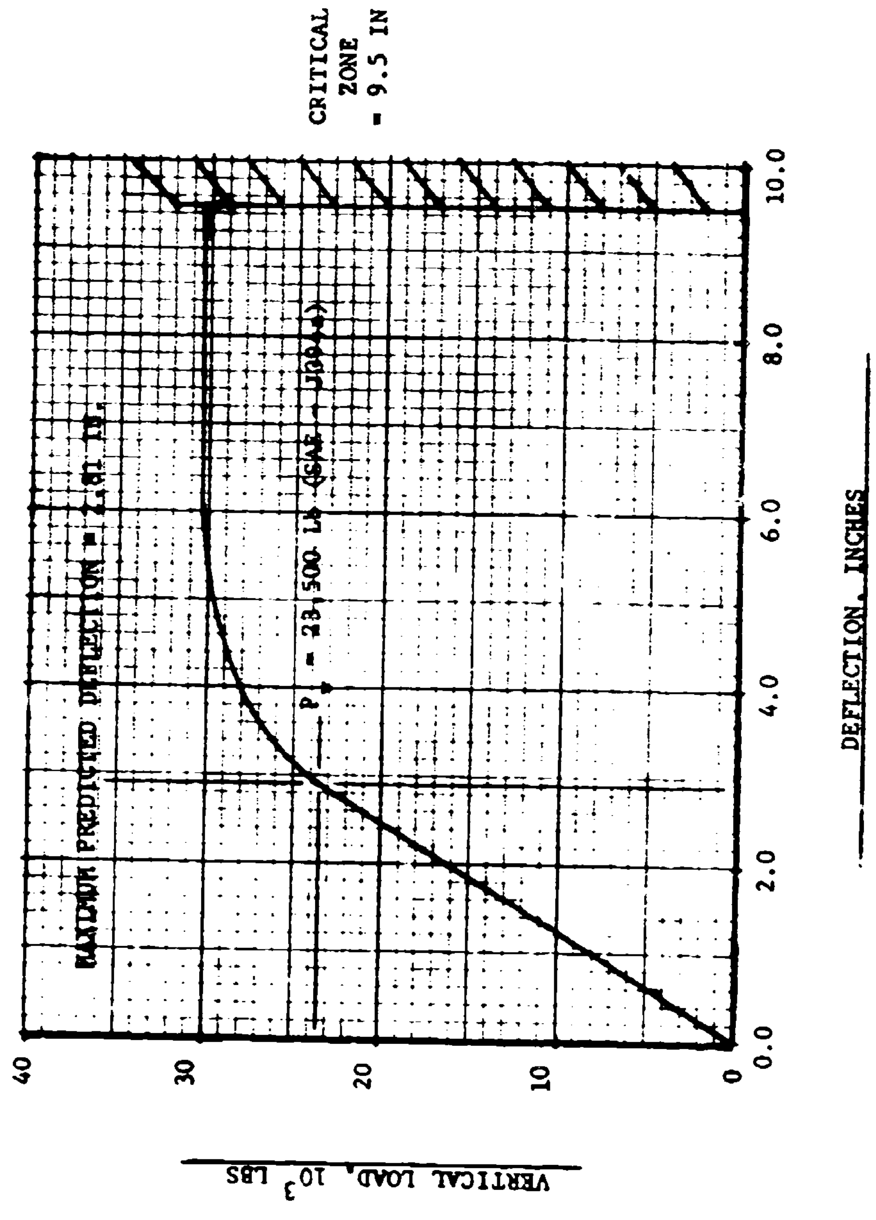


Figure 14 - Predicted ROPS Vertical Load Deflection

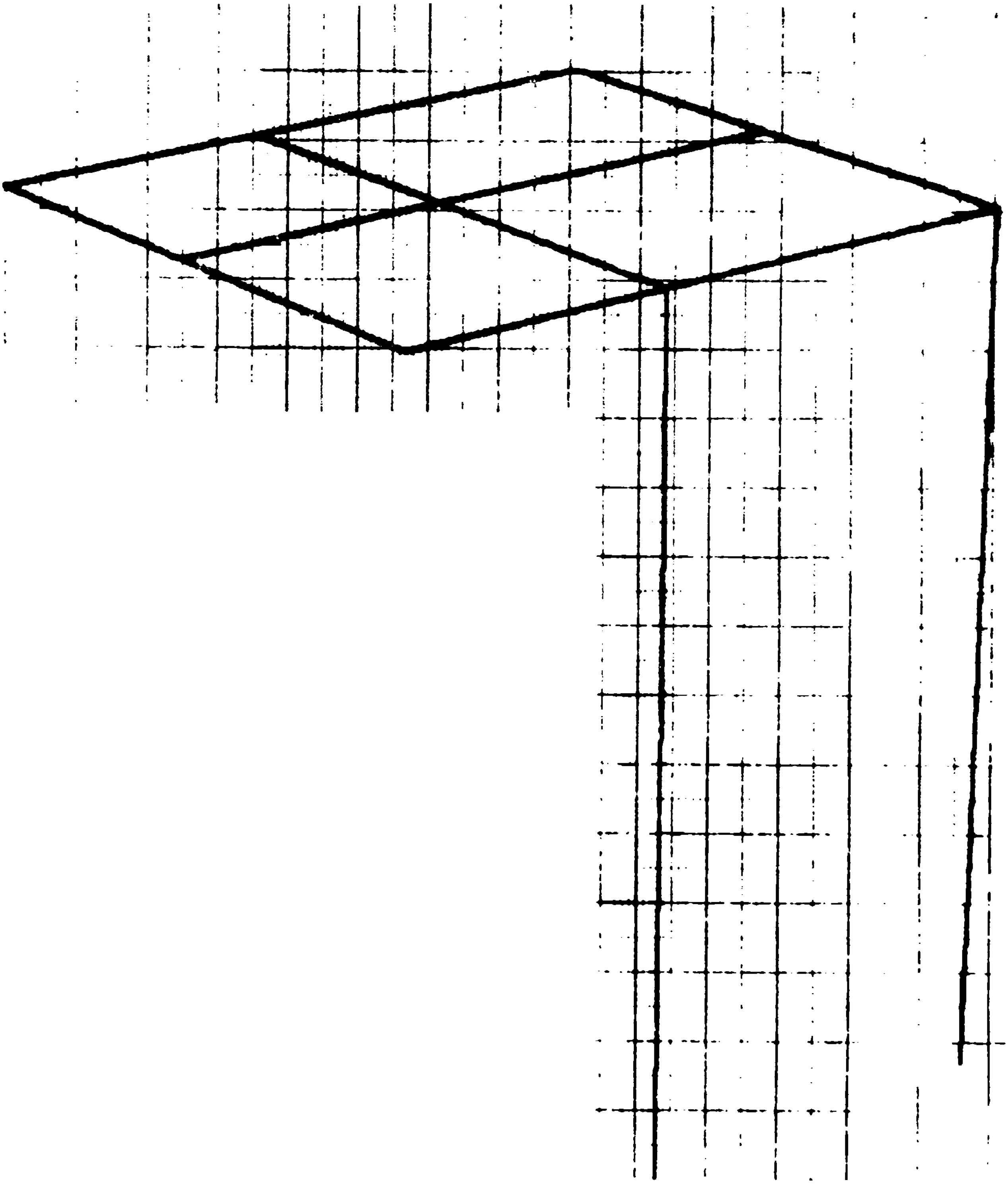
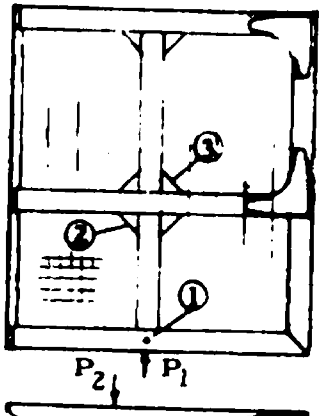
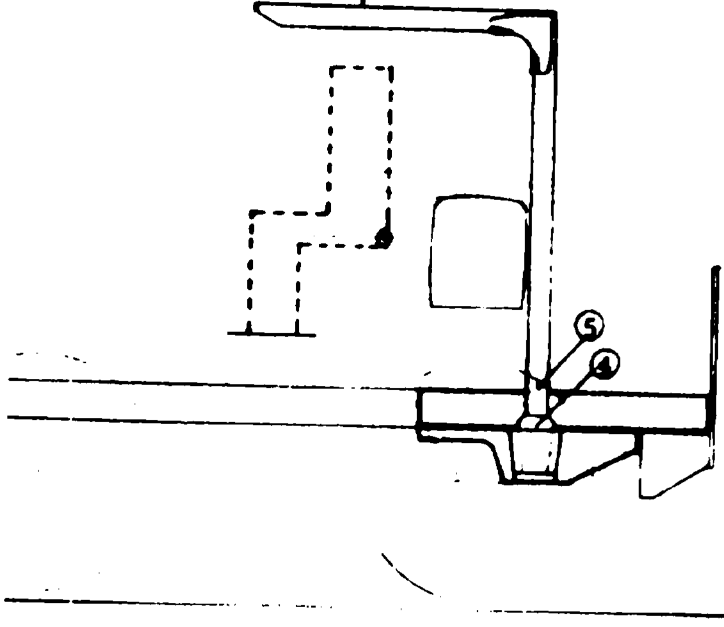


Figure 15 - 6K ROPS Computer Model



LOCATION	STRESS	ALLOWABLE	F.S.
DUE TO P_1 =	31,500		
①	15,700 lbs (col)	38,000 col.	2.42
②	15,300 psi	38,000 F_{ty}	2.49
③	6,750 psi	38,000 F_{ty}	High
④	71,600 psi	105,000 F_{bu}	1.47
DUE TO P_2 =	23,500 LBS		
⑤	47,000 psi	61,000 F_{by}	1.30



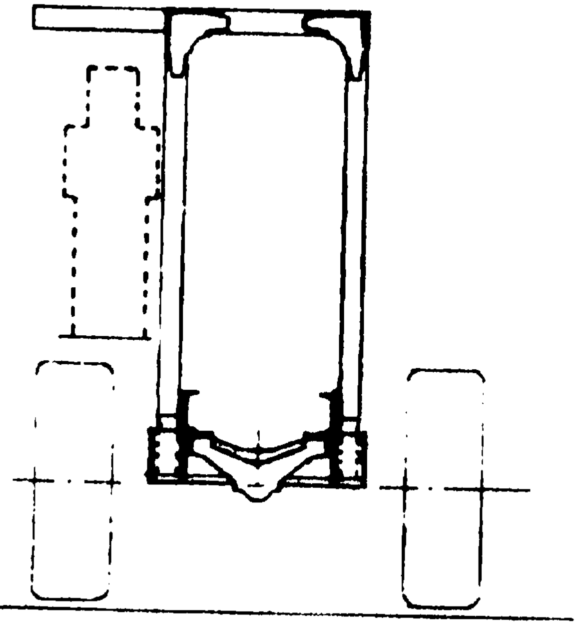
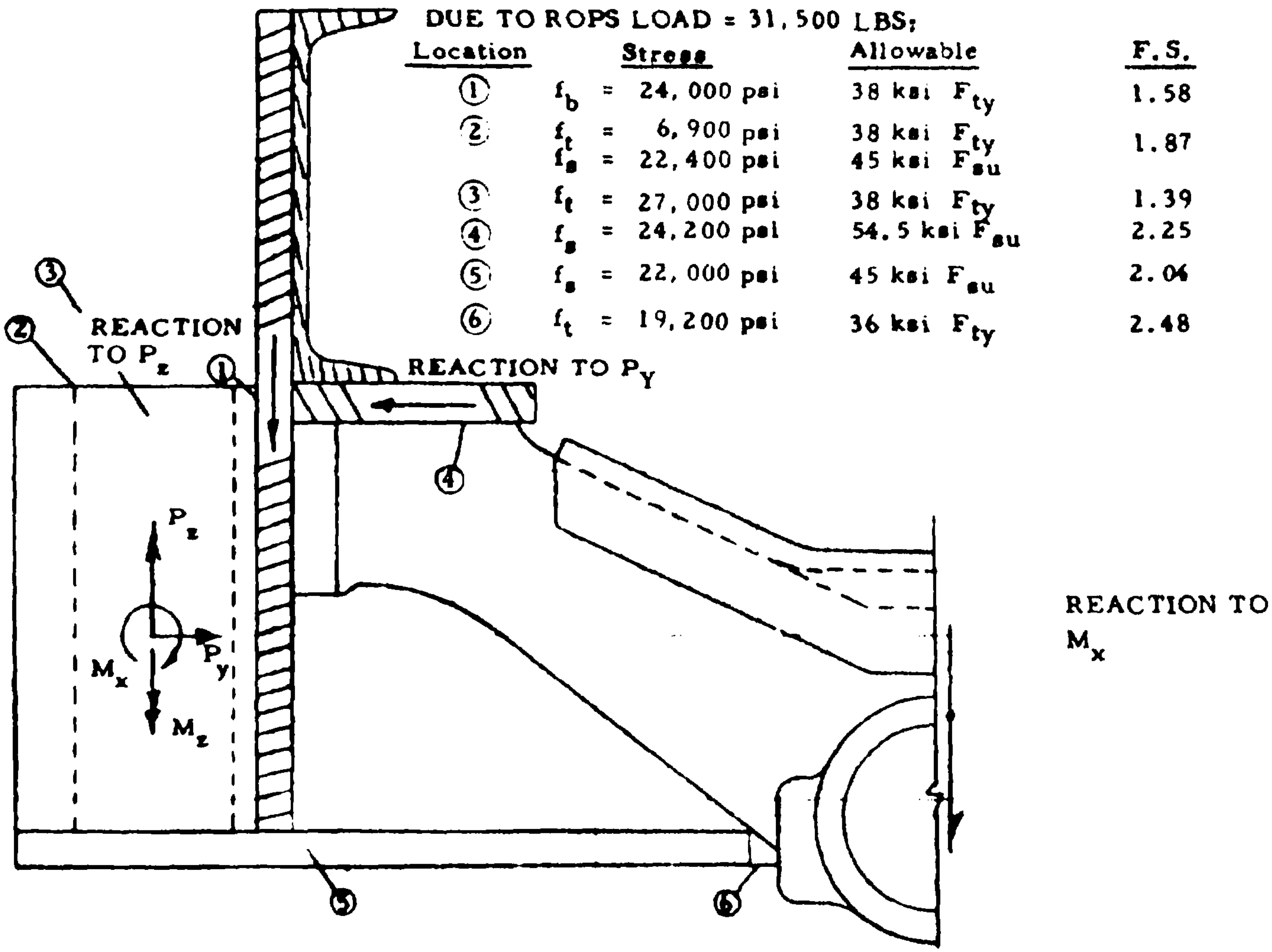


Table 1 - ROPS Stress Summary



DUE TO ROPS LOAD = 31,500 LBS:

Location	Stress	Allowable	F.S.
1	f_b = 24,000 psi	38 ksi F_{ty}	1.58
2	f_t = 6,900 psi f_s = 22,400 psi	38 ksi F_{ty} 45 ksi F_{su}	1.87
3	f_t = 27,000 psi	38 ksi F_{ty}	1.39
4	f_s = 24,200 psi	54.5 ksi F_{su}	2.25
5	f_s = 22,000 psi	45 ksi F_{su}	2.04
6	f_t = 19,200 psi	36 ksi F_{ty}	2.48

Table 2 - Frame Stress Summary

FRAME LOADS	LOCATION	STRESS	ALLOWABLE	F.S.
Px = 25,000 LB	①	f_t = 22,000 PSI	36,000 F_{ty}	1.64
Py = 15,000 LB	②	f_s = 16,000 PSI	37,000 F_{su}	2.32
Pz = 67,200 LB	③	f_t = 15,000 PSI	36,000 F_{ty}	2.40
My =625,000 IN-LB				
Mz =229,000 IN-LB				
Mx (CARRIED BY AXLE MOUNT)				

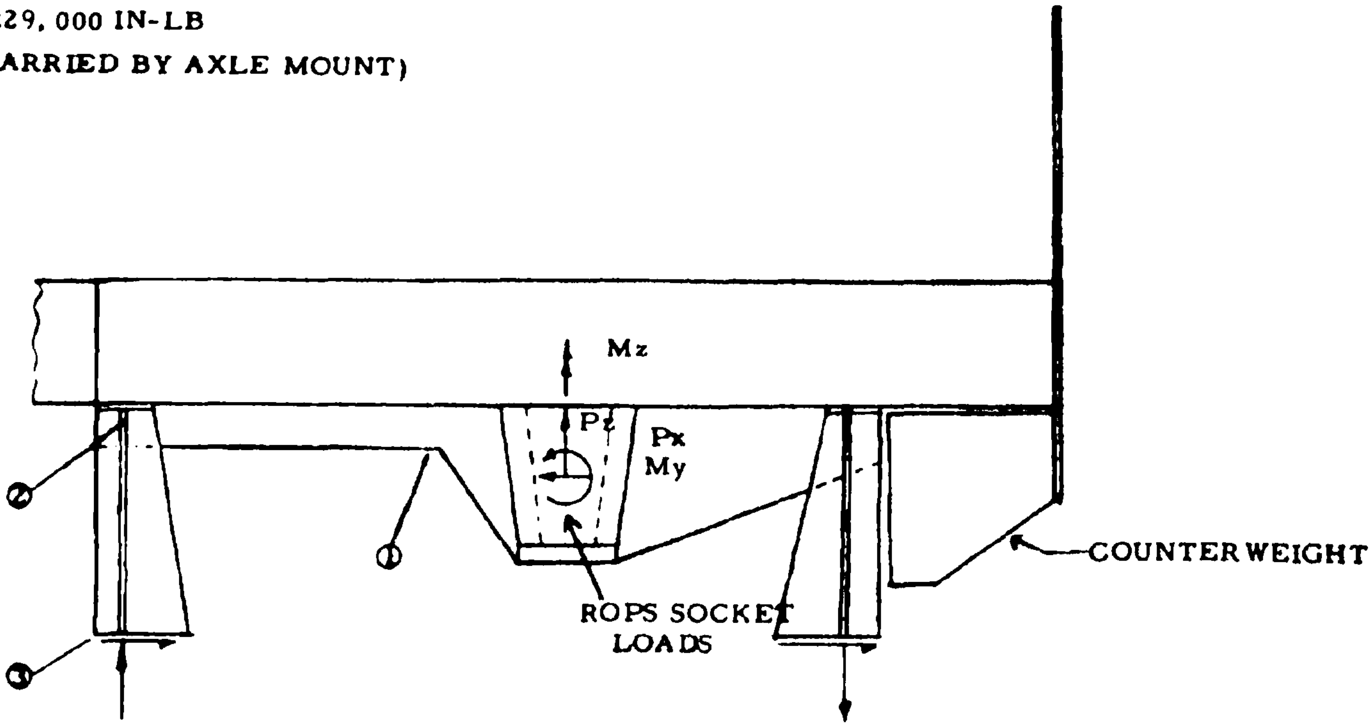


Table 3 - Frame Stress Summary (Cont'd)

Location 1 on Table 3 shows the expected frame stress for the side load test.

Location 2 and 3 are tie down stresses.

A possible increase in rear axle stress level due to additional ROPS weight was considered. When contacted by the USAMERDC representative, Clark, the axle manufacturer could see no difficulty in the additional axle loading. No additional analysis was conducted since inadequate definition of structural detail and load factors was available.

5.1.2.3 Comparison With Test Results

A comparison of the predicted side load to the measured test side load is shown in Figure 16.

Figure 16 shows more stiffness was obtained during the test in the elastic part of the side load deflection curve than predicted by the adjusted frame socket prediction curve. This occurred because the development 6K ROPS conical socket developed more fixity than obtained from the caterpillar ROPS rectangular socket which the method for the predicted elastic curve was based upon.

The reduced ultimate capability obtained from the test compared to predicted is discussed in Section 6.4 of the Appendix, "Analysis of Development Test Results". In summary, it shows the reduced ultimate capability was largely due to an unexpected influence of actuator rotation on the side load test. Normal rotation of the ROPS roof causes the side load actuator to deflect forward at the point where it attaches to the roof. With the other end of the actuator pivoting about a fixed point, the actuator rotates and develops a forward component load relative to the vehicle. This forward actuator load causes an additional bending moment at the lower end of the ROPS vertical legs. As a result, the ROPS plastic hinge bending moment is developed at a side load which is lower than would be obtained without actuator rotation. Only a 2% additional reduction in side load capability was due to material strength.

A comparison of the predicted vertical load to the measured test vertical load is shown in Figure 17. Except for a slight initial sag in the test vertical load deflection curve, the elastic curve matches the predicted curve very closely. The initial sag is due to socket clearance which permits rotation of the foot within the socket. The reduction in strength obtained in the vertical load test at large deflections is contributable to actuator rotation. Actuator rotation causes a significant increase in moment arm distance between the actuator line of action and the bottom of the ROPS tube. This test data will be studied in detail for the 10,000 lb forklift application where more vertical load capability is required.

Maximum frame reinforcements stress obtained from strain gage data is at gage No. 29. This is located at location 1, Table 3. Expected stress was f_t = 22,000 psi at 31,500 lb side load. Actual stress obtained was 13,300 psi at 24,000 lb side load. Extending this stress to 31,500 lb side load would produce 17,500 psi stress or predicted stress level was 25% conservative.

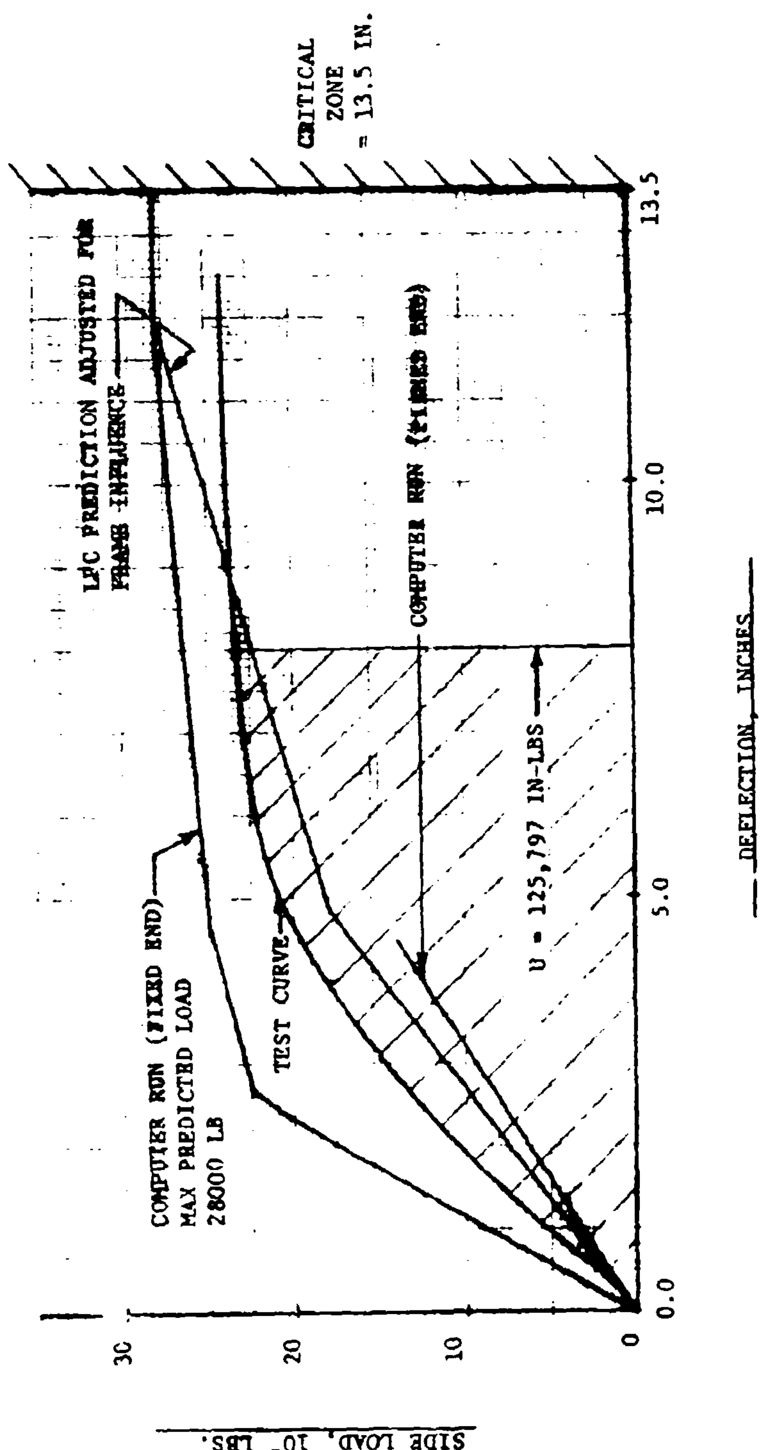


Figure 16 - Comparison of ROPS Side Load Deflection to Prediction

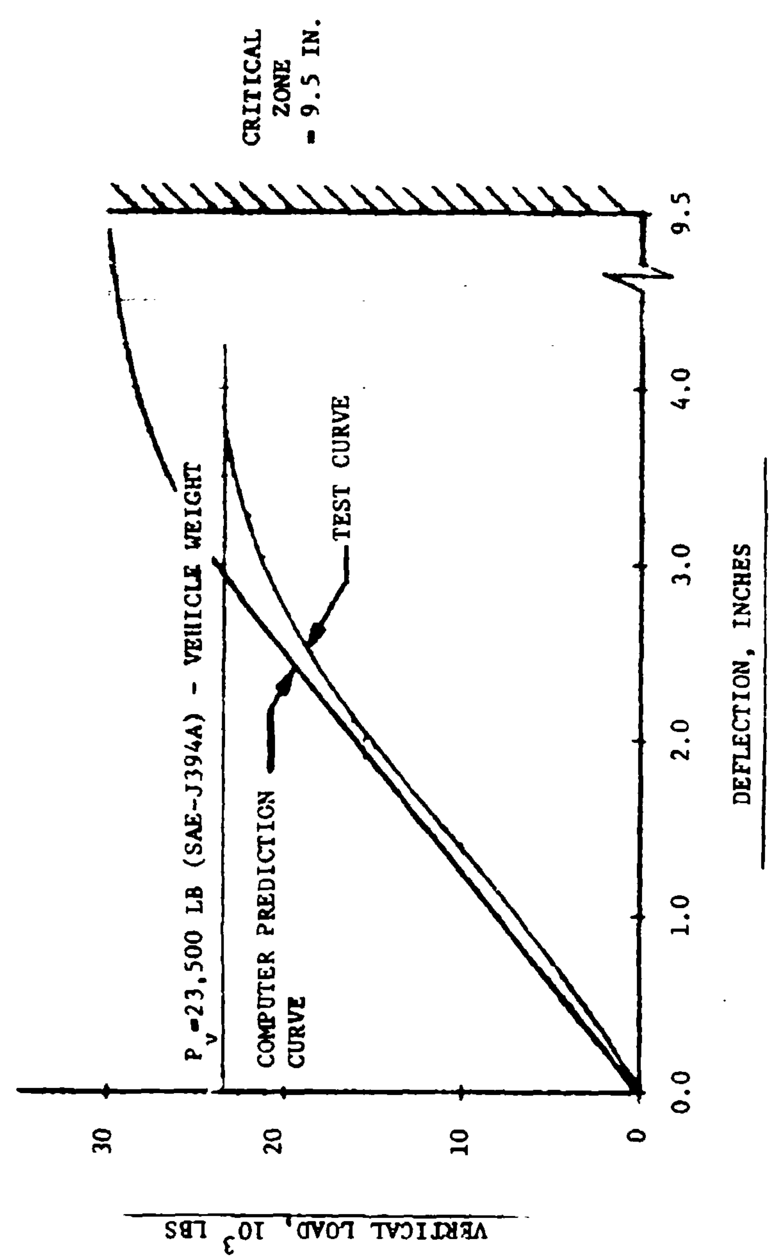


Figure 17 - Comparison of ROPS Vertical Load Deflection To Prediction

Maximum ROPS foot socket stress obtained was 14,800 psi at Gage No. 33. This is located at Location 3. Using the same procedure as above, predicted stress level of 27,000 psi was 39% conservative. Actuator rotation is accredited for this probable excessive conservatism because it tended to unload the critical right hand side socket.

Gage No's 20 and 24 recorded 1840 μ in/in and 1960 μ in/in strains in the ROPS curved gussets. This is well within material strain at yield strength of 3300 μ in/in and well within material elongation of at least 200,000 μ in/in but in excess of material proportional limit strain of 1300 μ in/in. Therefore, instrumentation indicates there was no danger of gusset failure, however, the gussets would be unable to develop much more load.

5.1.3 Fabrication

The Preliminary Design Review (PDR) for the 6K Development ROPS was held at LPC on April 4 and 5 with Mr. Bill Stewart, Contracting Officer's Representative, USAMERDC. Authority to proceed with fabrication of the Development ROPS and reinforcement hardware was granted at this time. Bids were received and the fabrication contract awarded to Tube-Lok Products, Portland, Oregon on April 9, 1973. Fabrication was completed on 4 May. Figures 18, 19 and 20 are photographs of the ROPS, foot, and socket-reinforcement details as they were received at the Potrero Test Facility.

5.1.4 Testing

The development testing for the 6,000 lb forklift ROPS consisted of a series of tests to characterize FOPS mesh and tests of the development unit to SAE requirements. Overload tests were also conducted in the side and vertical directions.

5.1.4.1 Falling Object Protective Structure (FOPS) Tests

The design selection of steel mesh to provide FOPS protection was based on the need for good overhead visibility, a requirement for forklift operation. Since steel mesh had not been used previously in this application, test results were not available. Also, analytical predictions were not considered to be reliable since the mesh weave complicates the geometry and makes stiffness predictions difficult.

A test set-up was built to charecterize the wire mesh to meet SAE J231 FOPS requirements. The test stand was made with 4 x 4 x 1/4 square tubes spaced to stimulate the support members of the ROPS roof.

Five drop tests were conducted, and the results are summarized in Table 4. Tests #2 and #3 demonstrated adequate penetration resistance by passing the 17 feet drop, but neither of the steels met the [illegible] ft-lb Charpy Vee Notch Impact test requirement. Figure 21 is a photograph of the Test #3 mesh after the 17 feet drop. Hot rolled 8620, a steel which exhibits strength and elongation properties similar to C1018, was used for the development ROPS test.

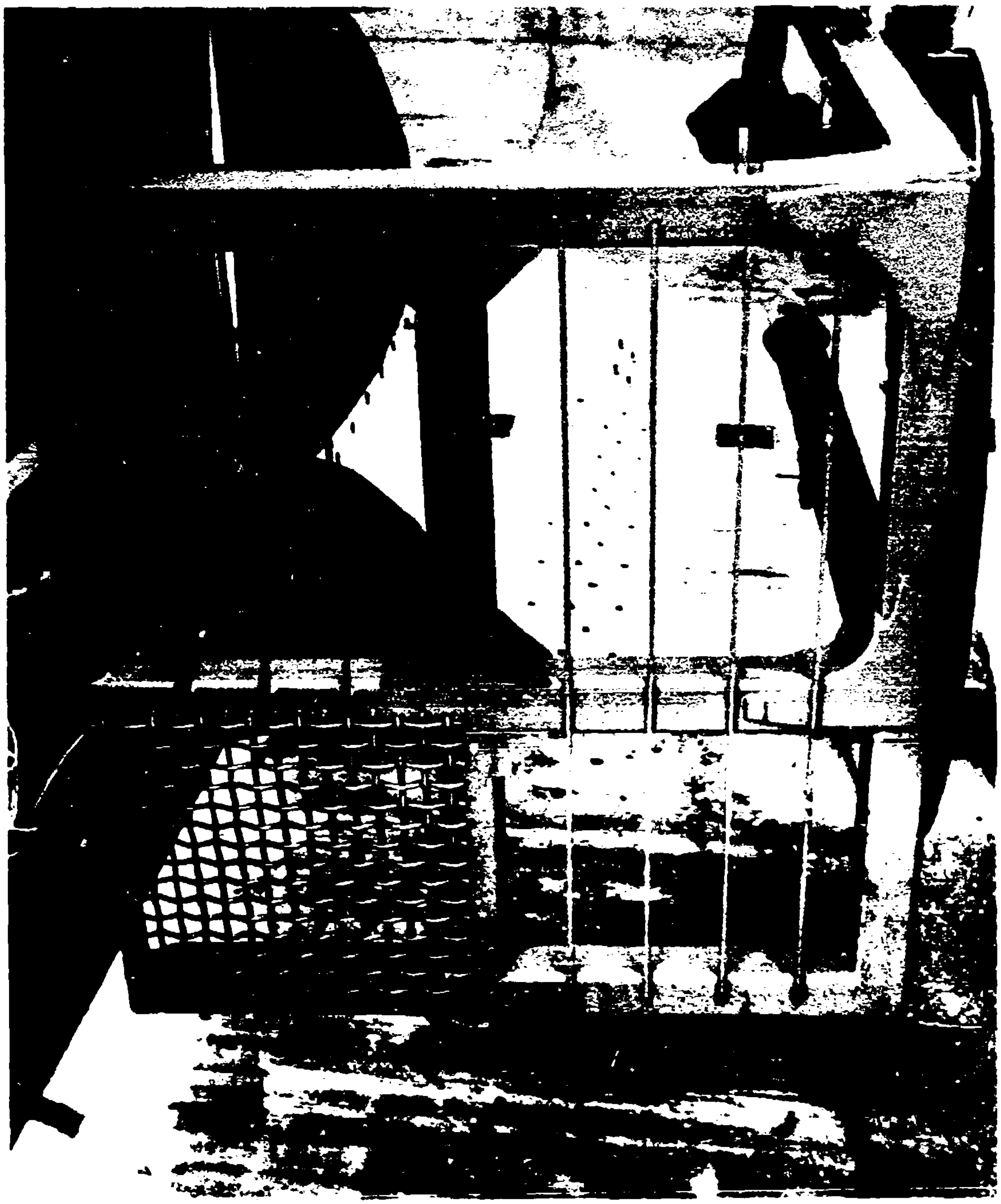


Figure 18 - Development ROPS

Figure 19 - Development ROPS Foot Detail

10323

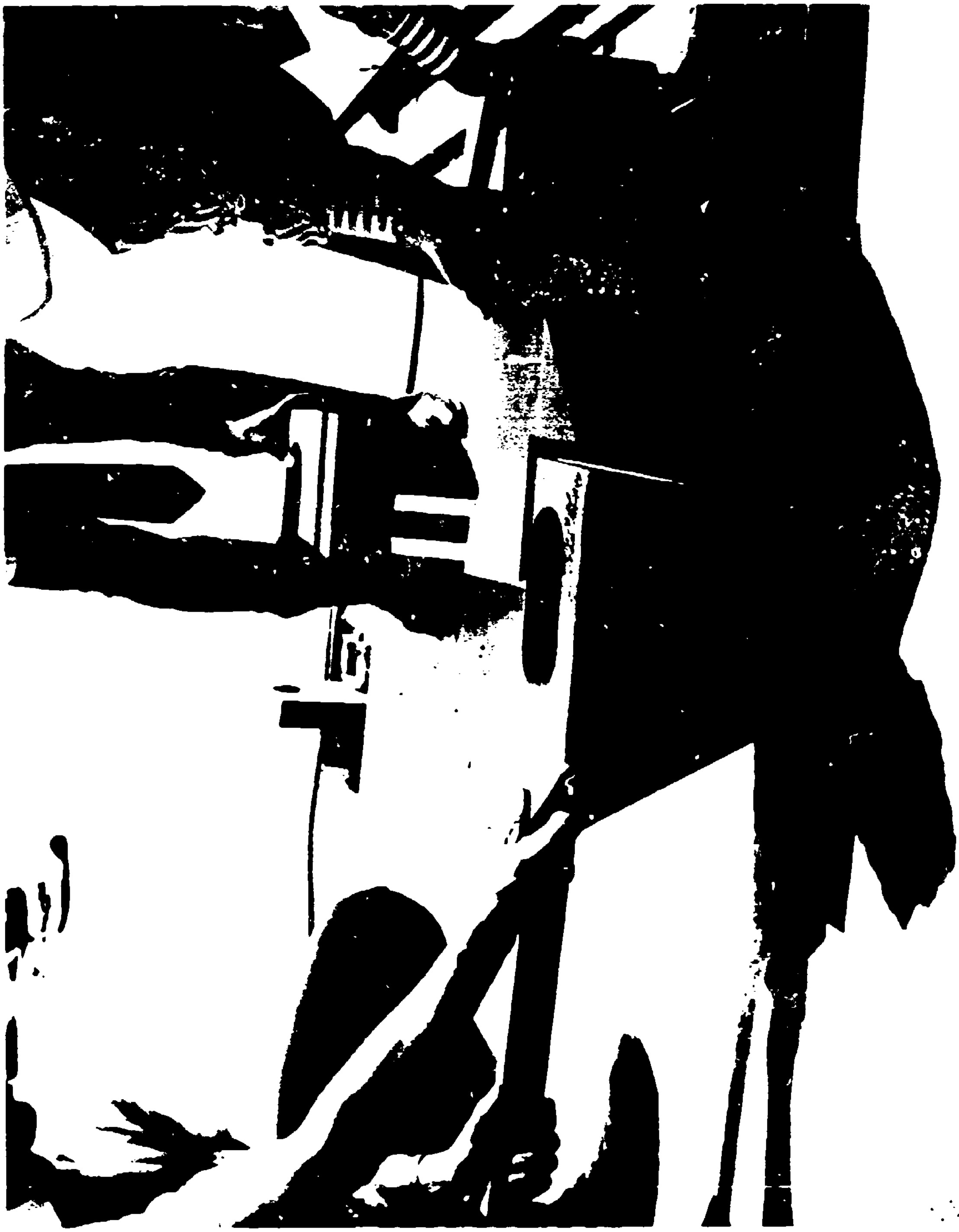


Figure 20 - Development ROPS Socket-Reinforcement

10340

TEST NO.	MESH SIZE	MATERIAL	DROP HEIGHT	TEST RESULTS
#1	2 x 2 x 5/16	Spring Steel	17	Weight penetrated mesh
#2	2 x 2 x 1/2	"	17	No penetration
#2A	2 x 2 x 1/2	"	23	Weight penetrated mesh
#3	2 x 2 x 1/2	C1018	17	No penetration
#3A	2 x 2 x 1/2	"	20	Weight penetrated mesh

Table 4, FOPS Test Results

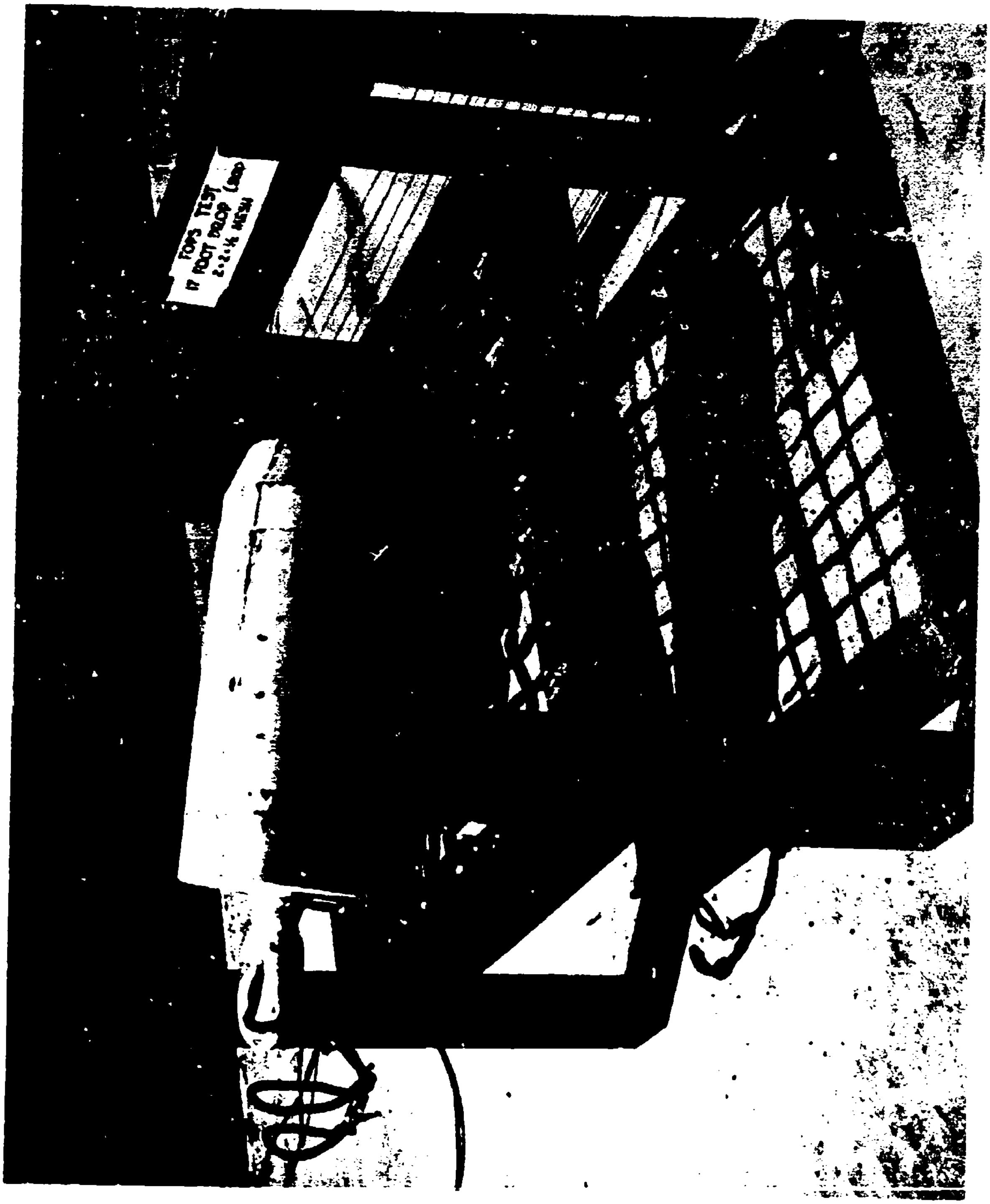


Figure 21 - FOPS Test #3 Post-Test Condition

10341

5.1.4.2 ROPS Installation for Development Test

The ROPS, mounting brackets and frame reinforcement details were installed to the forklift chassis in preparation for static testing. A problem with welding vehicle frame reinforcements was uncovered during reinforcement installation associated both with a lengthy installation time and frame distortion.

Reinforcements were welded to the chassis by a certified welder. Approximately 72 manhours were required to complete the welding specified in the installation assembly, Drawing No. 299025. 79 lbs of weld material were deposited, one quarter of which was required to weld reinforcement to the axle mount as shown in Figure 22 to permit this member to carry loads across the vehicle. The remainder of the welds were used to join reinforcement members and to attach them to the 9-inch channel section of the vehicle frame as shown in Figure 23. The installation time and weld material can be reduced slightly by modifying the weld preparation chamfers, but the concept of reinforcing frame members will require considerable welding.

A problem with controlling distortion in the chassis was encountered during reinforcement attachment. At the location of the mounting brackets the 9.0 inch chassis side channels had warped approximately 0.5 inch outward at the top flange. Distortion was due primarily to rotation of the channel caused by weld shrinkage of the large weld near the channel base. Some channel distortion was also noted in areas forward and aft of the mounting brackets.

The weld distortion of the channels caused cracking of the engine support brackets and interference with ROPS installation. Attempts to straighten the chassis were unsuccessful, therefore grinding approximately 0.25 inch from the side plate reinforcements was required to permit installation of the ROPS. Removal of this material was considered to have negligible effect on test results.

5.1.4.3 ROPS Development Test

Static development testing was performed with the ROPS and reinforcements installed on the Type "H" 6K Forklift on May 29. The tests were witnessed by W. Stewart and S. Newman of USAMERDC. The unit passed successfully all SAE requirements. The testing (in sequence conducted) with significant requirements and results is summarized as follows:

1. A 500-lb weight was dropped 17 feet onto the steel mesh on top of the ROPS in compliance with the FOPS requirements of SAE recommended practice J231. The weight did not penetrate the top of the critical zone (SAE Recommended Practice J397a) 14.5 inches below the mesh. The maximum deflection measured from high speed movies was six inches. Permanent deformation of 1.38 inches was recorded after the test. Figures 24 and 25 show the pretest and post-test condition of the mesh and supporting structure. It should be noted that prior to this test, the 8620 steel mesh passed the 8 ft-lb at -20°F Charpy Vee Notch Test

Figure 22 - Development ROPS Axle Reinforcement Weld Detail

10329

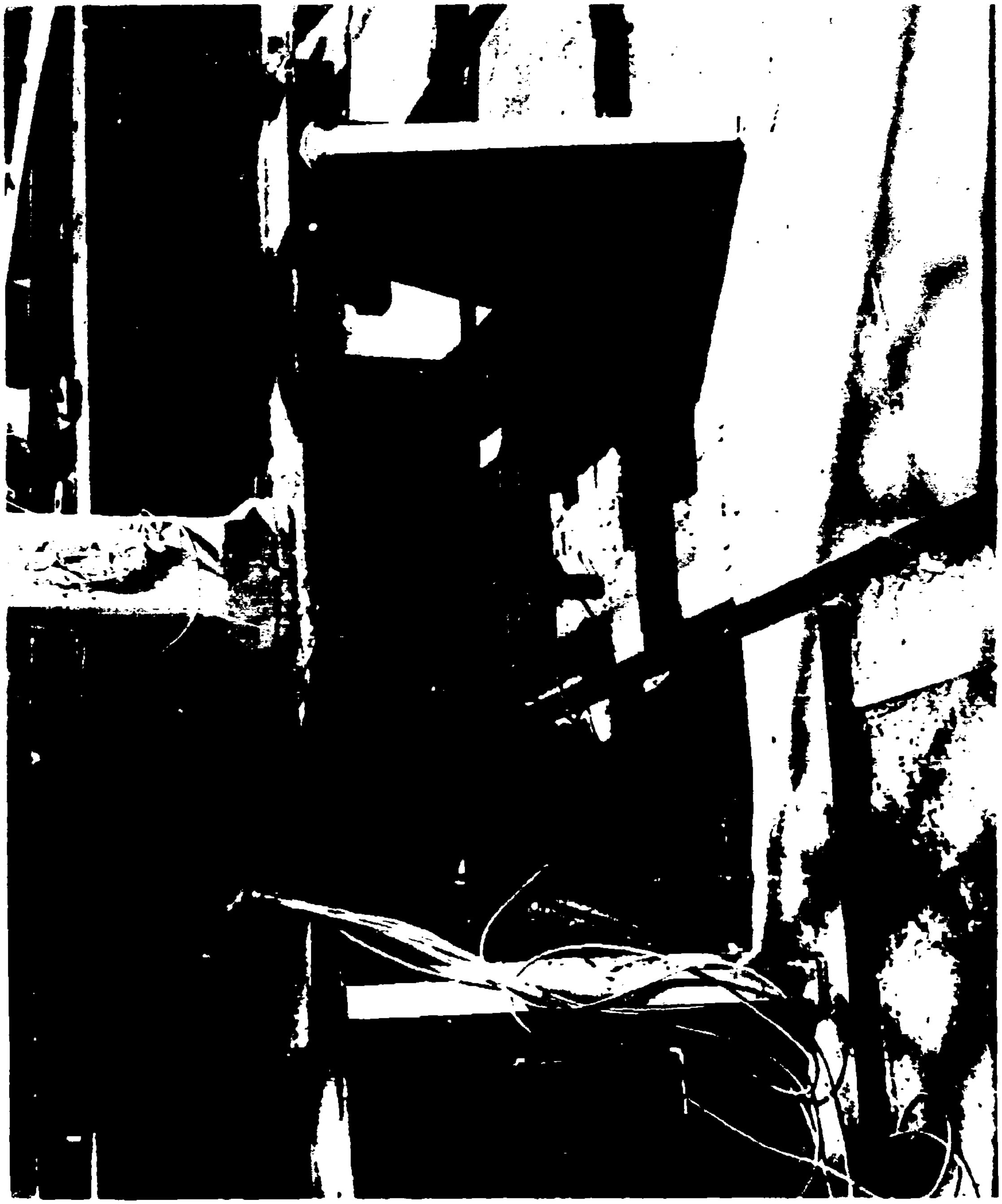


Figure 23 - Development ROPS Frame Reinforcement and Attachment Weld

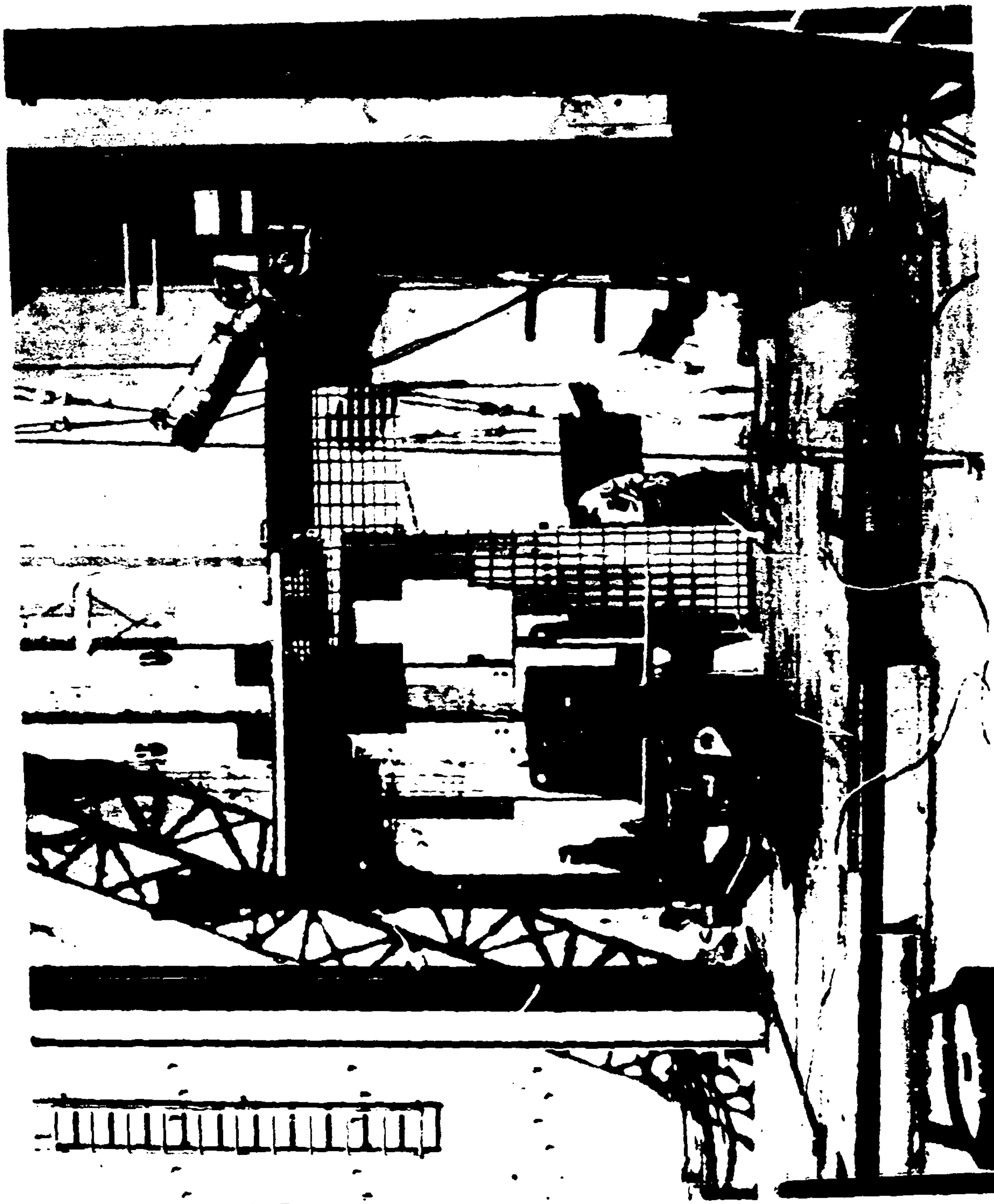


Figure 24 - Development ROPS Structure Before FOPS Test

10328

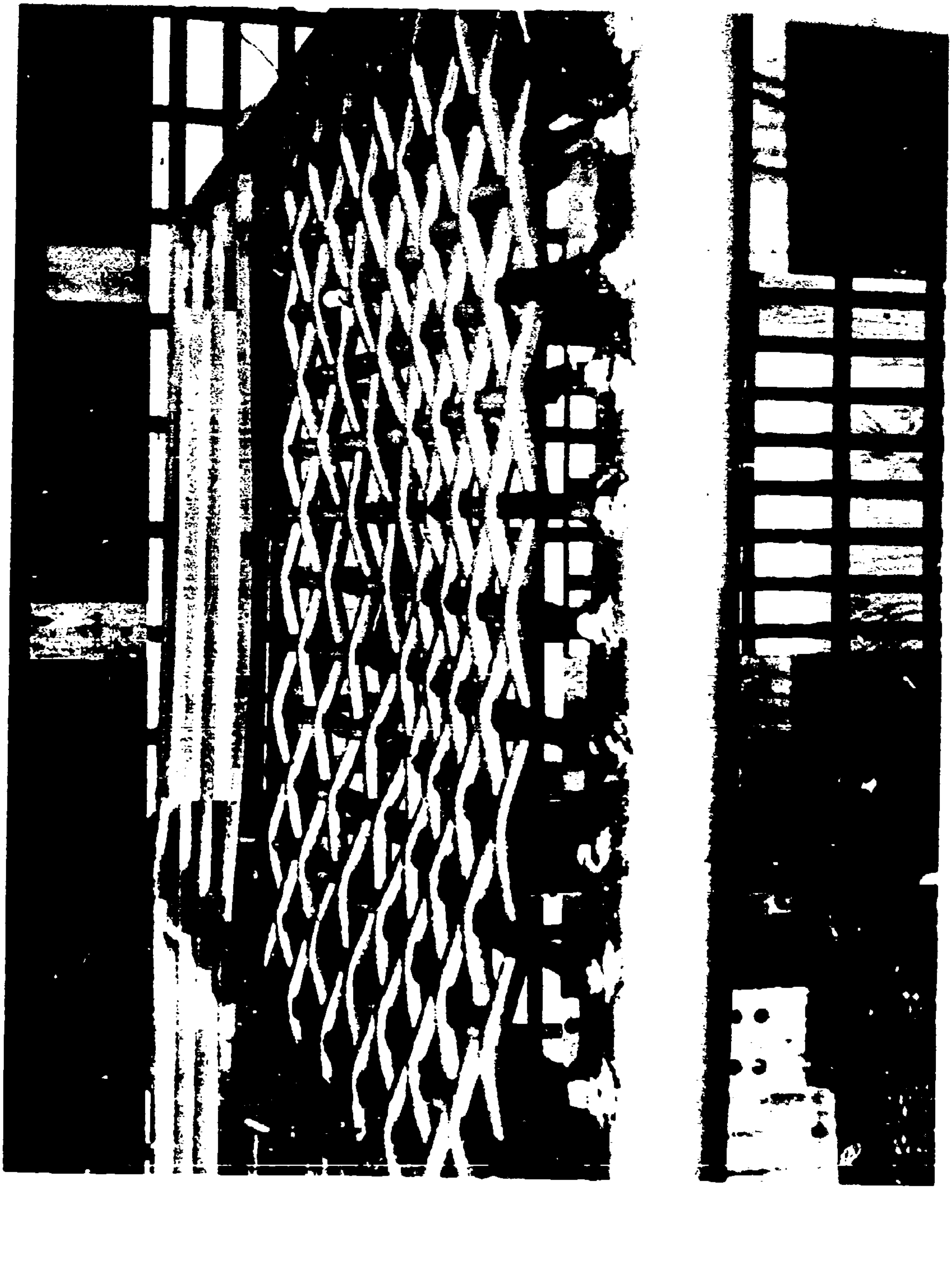


Figure 25 - Development ROPS Structure Following FOPS Test

requirement with a full size (10 mm x 10 mm) specimen.

2. The 15,000 lb side load and 122,000 in-lb side load energy requirements of SAE recommended practice J394a were met. Figure 26 shows that a load of 23,000 lb was reached at the required energy level and a deflection of 8.0 inches. Figures 27 and 28 show the pretest and post-test condition of the structure.

3. A vertical load of 23,500 lb, equal to the vehicle weight, was imposed at the geometric center of the ROPS roof as required by SAE recommended practice J394a. The deflections associated with this loading are shown in Figure 29. The structure under maximum loading is pictured in Figure 30.

4. The ROPS was then subjected to a side load overtest. The results showing a side load capability of 24,000 lb corresponding to a deflection of 12.5 inches is presented in Figure 31.

5. The ROPS was then subjected to a vertical load overtest to determine the load capability of the unit before the critical zone was invaded. Due to excessive rotation of the roof under load and the attendant variation in the load direction, data obtained in the test must be analyzed to accurately establish the load capability. This analysis will be conducted during the contract to retrofit a ROPS to the 10,000 lb forklift since a greater vertical load capability is required for this vehicle.

The complete Test Report is presented in Appendix 6.3, "Development Test Results". The results of all strain and deflection measurements are contained in this report.

5.2 Prototype Phase

5.2.1 Design

The design of the prototype hardware utilizes the development ROPS, but the ROPS attachment structure and chassis reinforcements are modified to permit bolting to the vehicle. The decision to use the development ROPS design was based on the development test results which showed that the unit passed successfully all of the applicable SAE criteria. Although the attachment structure to the chassis was changed significantly to accommodate the bolt-on concept the basic design features of the development unit were retained. This modification was needed to eliminate chassis distortion and reduce weld time incurred during installation of the development hardware.

5.2.1.1 Roll Over Protective Structure

The prototype ROPS is shown in LPC Drawing No. 299024, Revision D, Roll Over Protective Structure for 6K Forklift, Figure 32. As previously discussed, only minor changes were made to the canopy structure used for the development test.

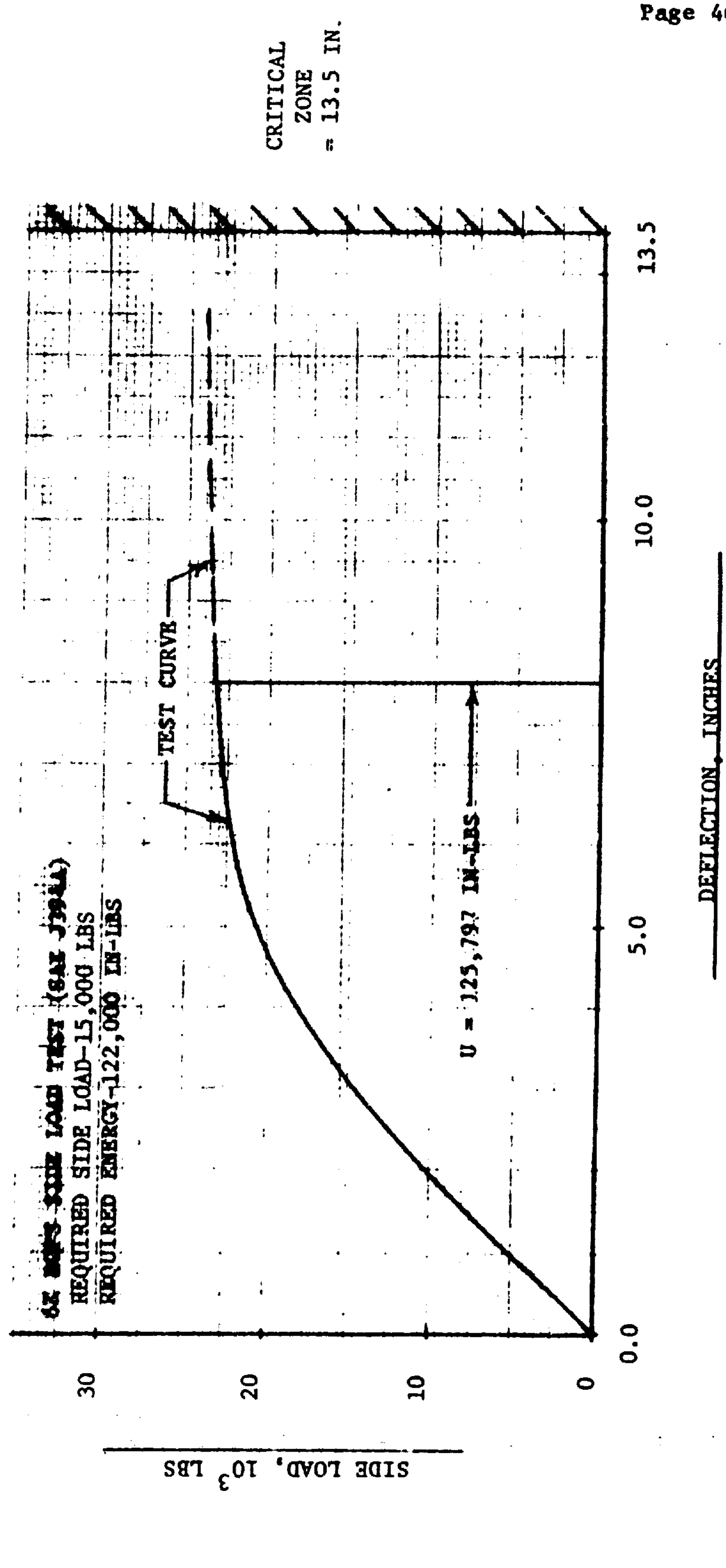


Figure 26 - Side Load Test Results

Figure 27 - Development ROPS Side Load Test Setup

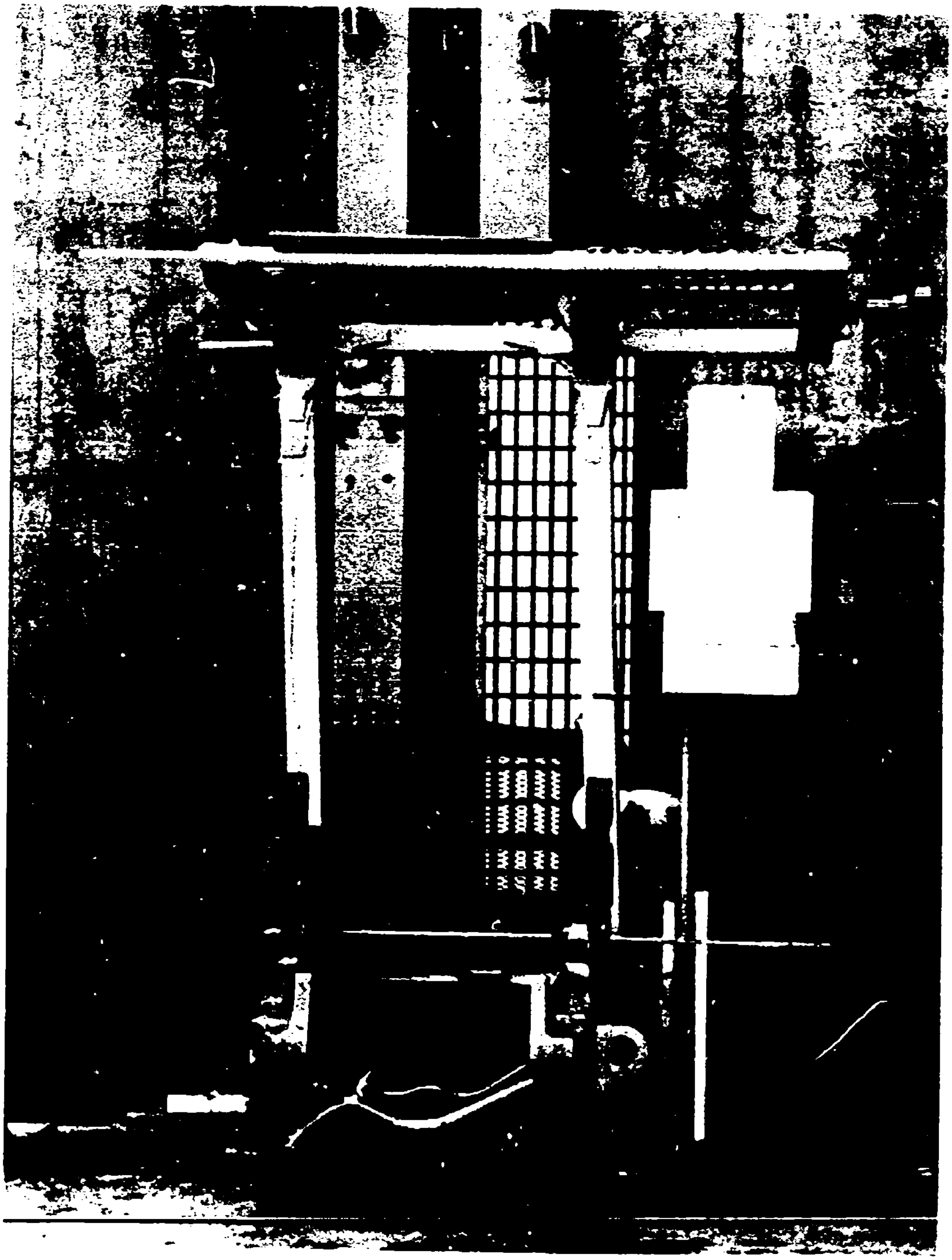


Figure 28 - Development ROPS After Side Load Test

10136

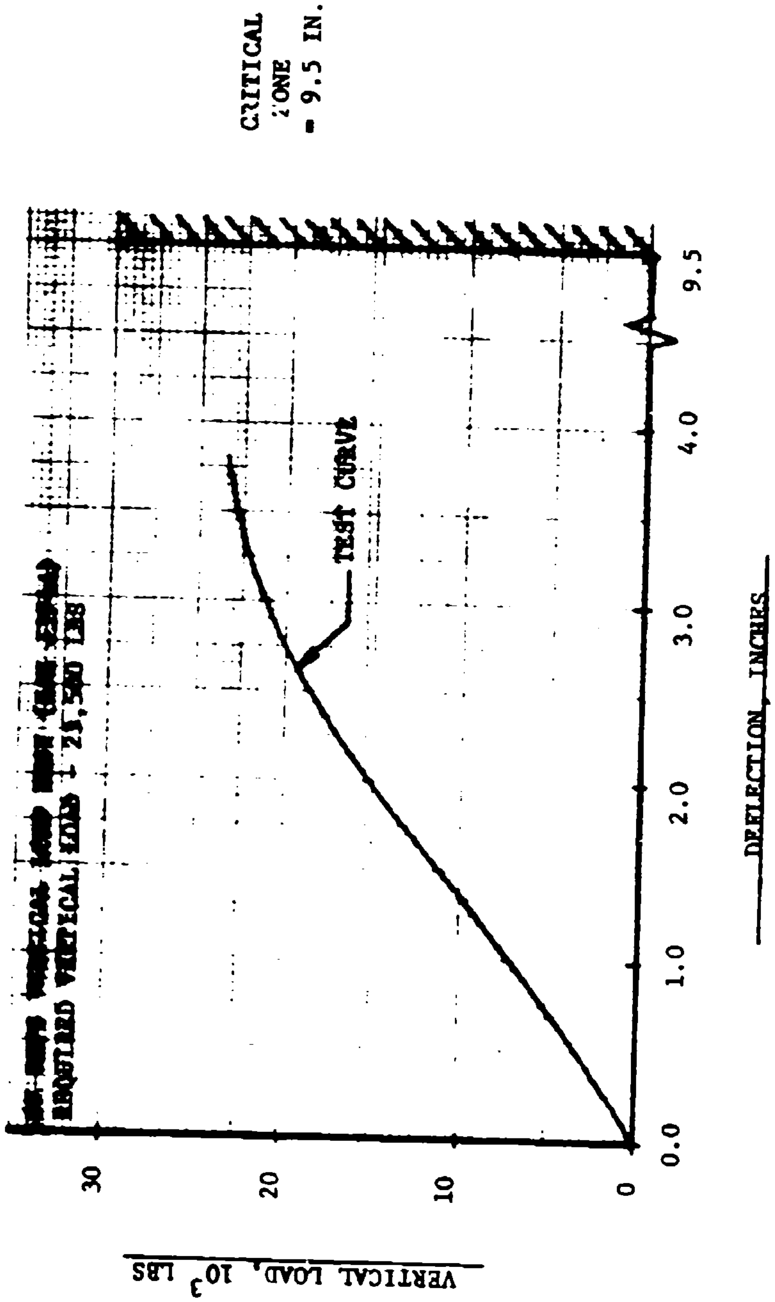
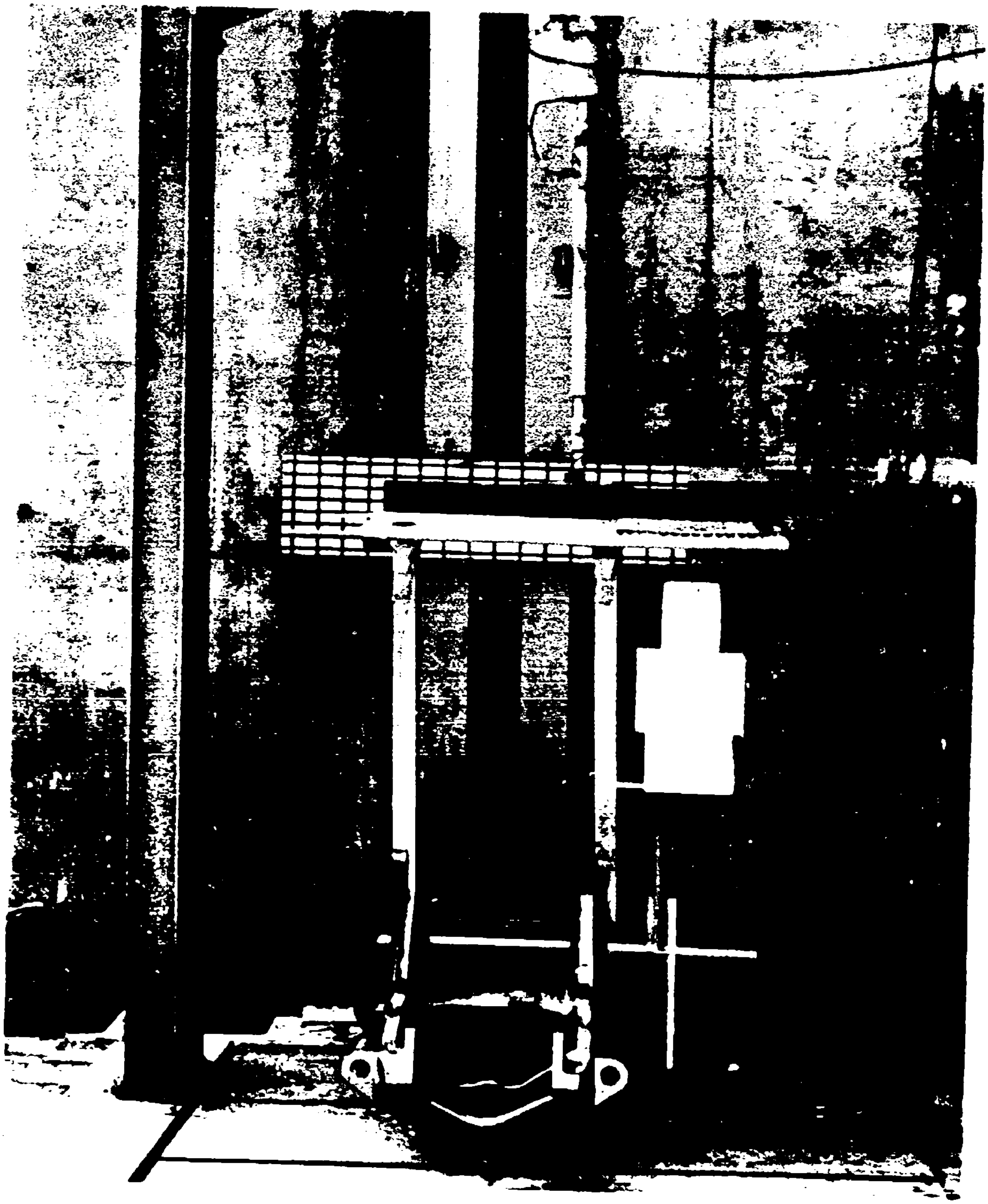


Figure 29 - Vertical Load Test Results



Figu.e 30 - Development ROPS Under Vertical Loading Requirement of 23,500 pounds

10319

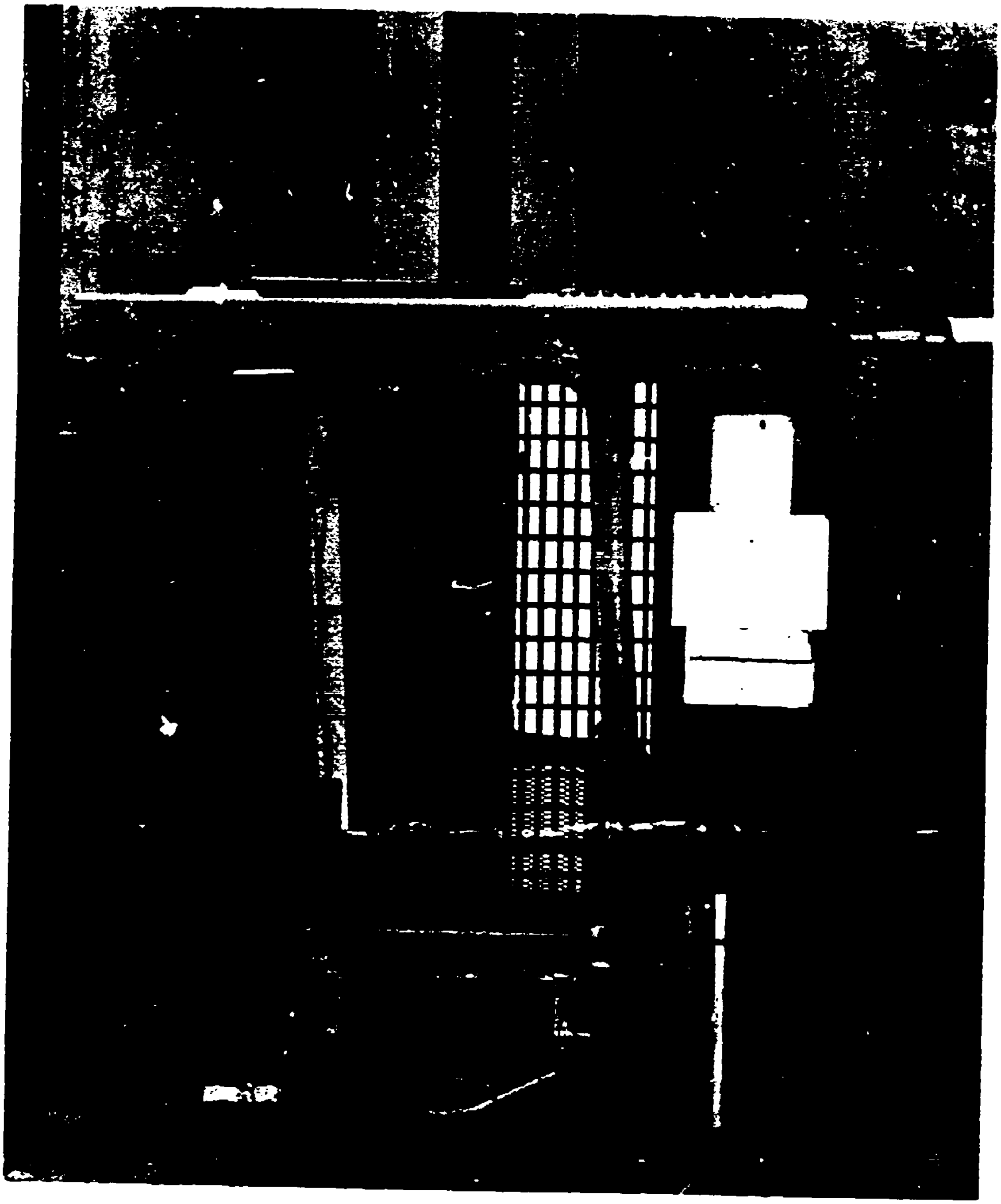


Figure 31 - Development ROPS at Maximum Side Load Overtest Condition

10330

The lifting lugs, located previously on the outboard surfaces of the main roof members, were moved to the inboard side of the same support members. The new position decreases the overall width to 75.205 inch from 83.375 inch. With this change the overall width of the vehicle was not increased by the ROPS retrofit. The lifting lugs are attached to the square tubing with welds on the top and bottom surfaces. These small welds will withstand the weight of the ROPS with a safety factor of three, but are sized to fail under the combined weight of the ROPS and vehicle. Therefore, the potential safety hazard of lifting the entire vehicle with the ROPS is avoided.

The configuration and material of the ROPS feet were changed to resolve clearance problems encountered during vehicle operation. During a fit-up check with a wooden mock-up critical areas of clearance were identified as follows:

1. The steering drag link located on the left side of the vehicle and the 299239-509 side plate reinforcements.

2. The steering cylinder located on the right side of the vehicle and the forward side of the socket.

3. The tire and 299239-105 top of socket at the outboard edge.

4. The tire and the outboard face of the 299024-137 post feet.

Each of these items was checked under various combinations of steering position and articulation of the vehicle. The design guidelines were to provide 0.5 inch clearance between vehicle components and the ROPS/reinforcement structure. An exception to this groundrule is the tire clearance which must be 1.0 inch to provide for the addition of tire chains. Actual clearances obtained are as follows:

1. An 0.5-inch clearance is provided for the steering drag link

2. The steering cylinder has 1.0 inch clearance

3. The tire clears the socket and post foot by 1.25 inch

The cross-section of the post feet was reduced to achieve a smaller socket. The width was reduced to 2.600 inch from 3.660 inch. The length of the feet was increased to 31.75 inch from 18.0 inch to permit shortening the square tubing to provide clearance with the tire.

A higher strength allowable was needed for the post feet to accommodate the higher applied stresses due to the reduced cross-section. The material was changed to AISI 4340 steel heat treated to 125,000 psi minimum ultimate tensile strength. To preclude weld cracking, special requirements for welding were specified in Note 12 of Drawing No. 2990240. This note added preheat, postheat and stress relieving requirements to the Welding Specification DPSF100.

A threaded hole was provided in the base of the post foot of the prototype unit to accept a cap screw to retain the foot in the socket. This concept offered several design simplifications to the development unit. The cap screw replaced the machined eye bolt and nut. The machined slot in the foot of the development unit was deleted. The tapped hole utilizes fabrication techniques more commonly used by ROPS manufacturers.

5.2.1.2 Attachment Structure

The ROPS attachment structure for the prototype unit is shown in LPC Drawing No. 299239, Revision E, 6K Forklift ROPS Bolt-on System Attachment Structure, Figure 33.

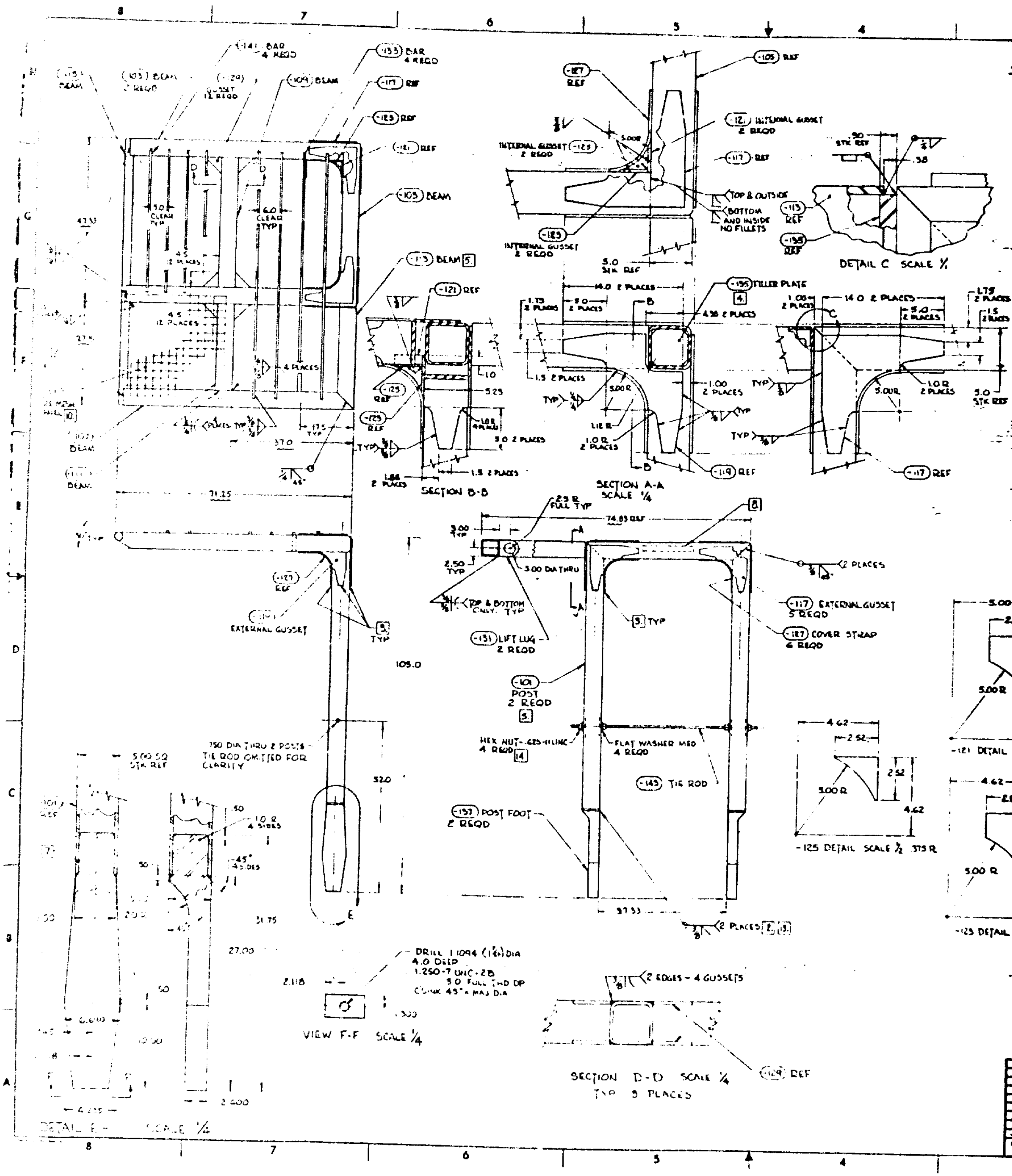
In the development unit, the frame and rear axle mount were strengthened by welding reinforcing elements to provide an adequate load path from the vehicle into the ROPS and to develop sufficient strength and stiffness to withstand the loads imposed on the ROPS. While making maximum use of the vehicle structure, this approach required considerable welding at the time of ROPS installation and the attachment of the long frame reinforcement member caused the 9-inch channel comprising the frame to deform. Because of the installation time and distortion, alternate approaches were investigated even prior to the development test. At the same time, modifications to reduce cost developed from the experience of fabricating the development unit were taken into account. The concept developed utilizes the forklift structure primarily as a load path between the vehicle and the ROPS. The axle housing is not utilized to transmit loads across the frame as in the development design. The attachment structure consists of integral mounting brackets and cross-over beam and frame reinforcement and attach plates.

The attach plates on one side are fabricated as part of the mounting bracket-beam unit. The other attach plate is assembled to the structure at the time of ROPS installation in order to accommodate vehicle frame width tolerances. At installation, the attach plate is welded to the mounting bracket at the proper location and 28 holes 3/4" in diameter are drilled into the frame in line with holes pre-drilled in the attach plates. Bolting completes the installation of the structure and the ROPS canopy then is attached to the mounting bracket in the same manner as in the development unit.

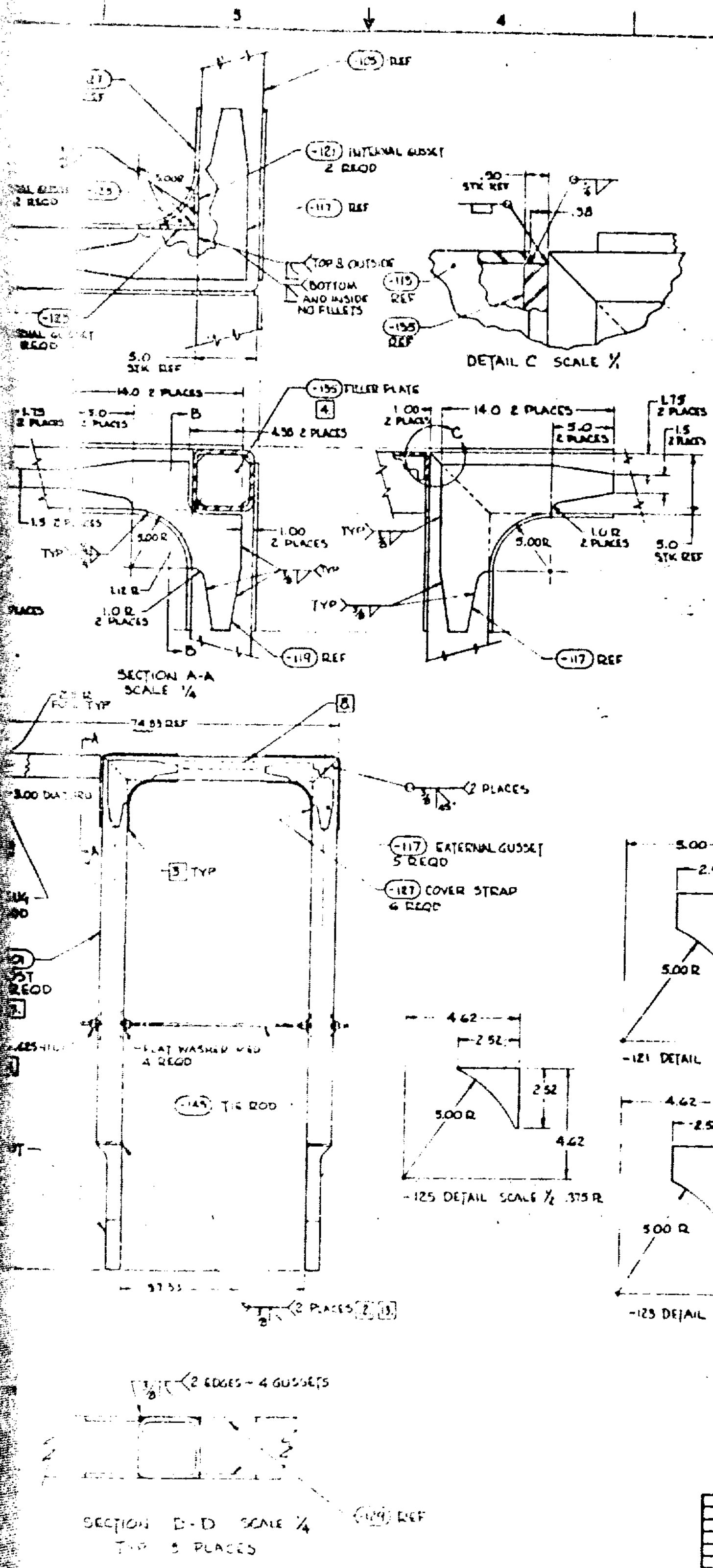
5.2.1.3 Resilient Pads

Noise suppression and vibration-shock reduction is provided with resilient pads specified in LPC Drawing No. 299029, Kit of Resilient Pads for ROPS for 6K Forklift, Figure 34. Pads are placed on all sides of the sockets to completely isolate the post feet from metal-to-metal contact with the sockets. In addition, washer pads are placed under the heads of the cap screws.

The resilient pad material is Fabreeka. This is a specially manufactured material composed of layers of tightly twisted, closely woven cotton duck impregnated with rubber. The physical properties of Fabreeka are suited to applications of shock, vibration and noise reduction.



SECTION B-B
SECTION A-A SCALE 1/4
DETAIL C SCALE 1/2
(-155) FILLER PLATE
(-121) INTERNAL GUSSET 2 REQD
INTERNAL GUSSET (-123) 2 REQD
INTERNAL GUSSET (-125) 2 REQD
(-105) BEAM
(-153) BAR 4 REQD
(-109) BEAM
(-113) BEAM
(-151) LIFT LUG 2 REQD
(-101) POST 2 REQD
(-117) EXTERNAL GUSSET 5 REQD
(-127) COVER STRAP 6 REQD
(-145) TIE ROD
(-157) POST FOOT 2 REQD
HEX NUT-.625-11UNC 4 REQD
FLAT WASHER MED 4 REQD
.750 DIA THRU 2 POSTS TIE ROD OMITTED FOR CLARITY
3.00 DIA THRU
74.83 REF
105.0
52.0
71.25
37.0
EXTERNAL GUSSET
DRILL 1.1094 (1 7/64) DIA 4.0 DEEP 1.250-7 UNC-2B 3.0 FULL THD DP
VIEW F-F SCALE 1/4
SECTION D-D SCALE 1/4 TYP 5 PLACES
-125 DETAIL SCALE 1/2
DETAIL E SCALE 1/4



NOTES:

1. WELDING PER DPSF100. FOR -137 SEE NOTE 12
2. GRIND FLUSH ALL WELDS COVERED BY GUSSETS.
3. OMIT WELDS ACROSS ENDS OF GUSSETS AND COVER-STRAPS.
4. TRIM CORNERS OF -135 TO FIT INTO -115.
5. SUGGESTED SEQUENCE FOR WELDING -115 TO -101
   a) WELD -135 INTO -115
   b) WELD -135 TO -101 AND FILL FLUSH WITH -115 ALL AROUND.
   c) WHEN WELDING -119 ON, FILL FLUSH ALONG EDGES ADJACENT TO -115.
6. STEEL PER AISI 4340, HEAT TREAT TO 125000 PSI ULTIMATE TENSILE STRENGTH.
7. MAX CLEARANCE .05, 4 SIDES. CHAM CORNERS OF -137, .25 x 45°
8. PERMANENT MARK DWG NO, APPLICABLE DASH NO, & SERIAL NO. IN AREA SHOWN.
9. APPLY 1 COAT INTERNATIONAL NU-PLATE F PRIMER TO -501, EXCEPT STUDS.
10. WELD -139 WIRE MESH PANEL OVER TOP OF STRUCTURE OVERLAPPING SQUARE MEMBERS BY 2.00±.25. OVERLAP FORWARD ROUND TUBE BY 1.25±.25. REMOVE OUTER STRAND, 4 SIDES OF PANEL. STRAIGHTEN EXTENDING STRAND ENDS AND WELD WITH DOUBLE .25 FILLET, LENGTH OF OVERLAP.
11. TOLERANCES: .XX = ±.06, .XXX = .030
12. TO WELD OR REPAIR WELD -137 TO -101, PERFORM THE FOLLOWING IN ADDITION TO THE REQUIREMENTS OF DPSF100:
   a. PREHEAT TO 550-650°F.
   b. INTERPASS TEMP – 550-650°F.
   c. POST HEAT – 550-650°F FOR 10 MIN.
   d. AFTER PART COOLS TO ROOM TEMP, STRESS RELIEVE AT 400-500° FOR 15 MIN.
13. AFTER STRESS RELIEF INSPECT THE WELD BY MAGNETIC PARTICLE OR DYE PENETRANT METHOD. NO CRACKS PERMITTED.
14. TIGHTEN NUTS HAND TIGHT WITHOUT SPRINGING POSTS.

C	(1-5) SEE DCN "C" JOB NO SBC-1007.		
D	(1) SEE DCN "D" JOB NO SBC-1007		

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE
4			HEX NUT, .625-11 UNC	STEEL		
4			FLAT WASHER, .625 MED	STEEL		
1		-145	THREADED ROD, .625-11 UNC 50.0 LONG	STEEL	EMSD105	
4		-141	BAR, ½ SQ × 41.33 LONG	STEEL	EMSD103	H7
✓			WELDING		DPSF100	
AR		NU PLATE F	PRIMER INTERNATIONAL PAINT CO (INC) 250 S. LINDEN AVE, SOUTH SAN FRANCISCO, CALIF.			
1		-139	WIRE MESH, 2x2, 36.5×31.0 .50 DIA WIRE	STEEL	8x10 H.R	F8
2		-137	POST FOOT 5.0×6.75×2.75	STEEL	6	C4
1		-135	FILLER PLATE .50 R, 4.5 SQ		EMSD103	G5
4		-133	BAR, ½ SQ × 68.33 LONG			H7
2		-131	LIFT LUG, .75 PLATE 5.0 × 5.5			E4
12		-129	GUSSET-TRIANGULAR .375 R, 4.5 × 4.5			H7
6		-127	COVER-STRAP .375 R, 5.25 × 18.0			D4
2		-125	GUSSET-INTERNAL .375 R, 2.7 × 2.7			H6
2		-123	GUSSET-INTERNAL .375 R, 2.7 × 4.1			G6
2		-121	GUSSET-INTERNAL .375 R, 3.1 × 4.1			H5
1		-119	GUSSET-EXTERNAL .375 R, 4.0 × 4.0			D7
5		-117	GUSSET-EXTERNAL .375 R, 14.0 × 14.0		EMSD105	D4
1		-115	BEAM-TUBING-2.5 DIA, .25 WALL, 74.85 LONG		EMSD104	H8
					299024	D
1		-113	BEAM-TUBING-5.0 SQ, .25 WALL, 27.5 LONG		EMSD104	G6
1		-111	BEAM-TUBING-5.0 SQ, .25 WALL, 22.5 LONG			E8
1		-109	BEAM-TUBING-5.0 SQ, .25 WALL, 37.33 LONG			H7
1		-107	BEAM-TUBING-5.0 SQ, .25 WALL, 70.[illegible] LONG			E8
1		-105	BEAM-TUBING-5.0 SQ, .375 WALL, 47.33 LONG			G6
2		-103	[illegible] TUBING-5.0 SQ .375 WALL, [illegible] LONG			H8
2		-101	[illegible] .375 WALL, 79.5	STEEL	EMSD104	D6

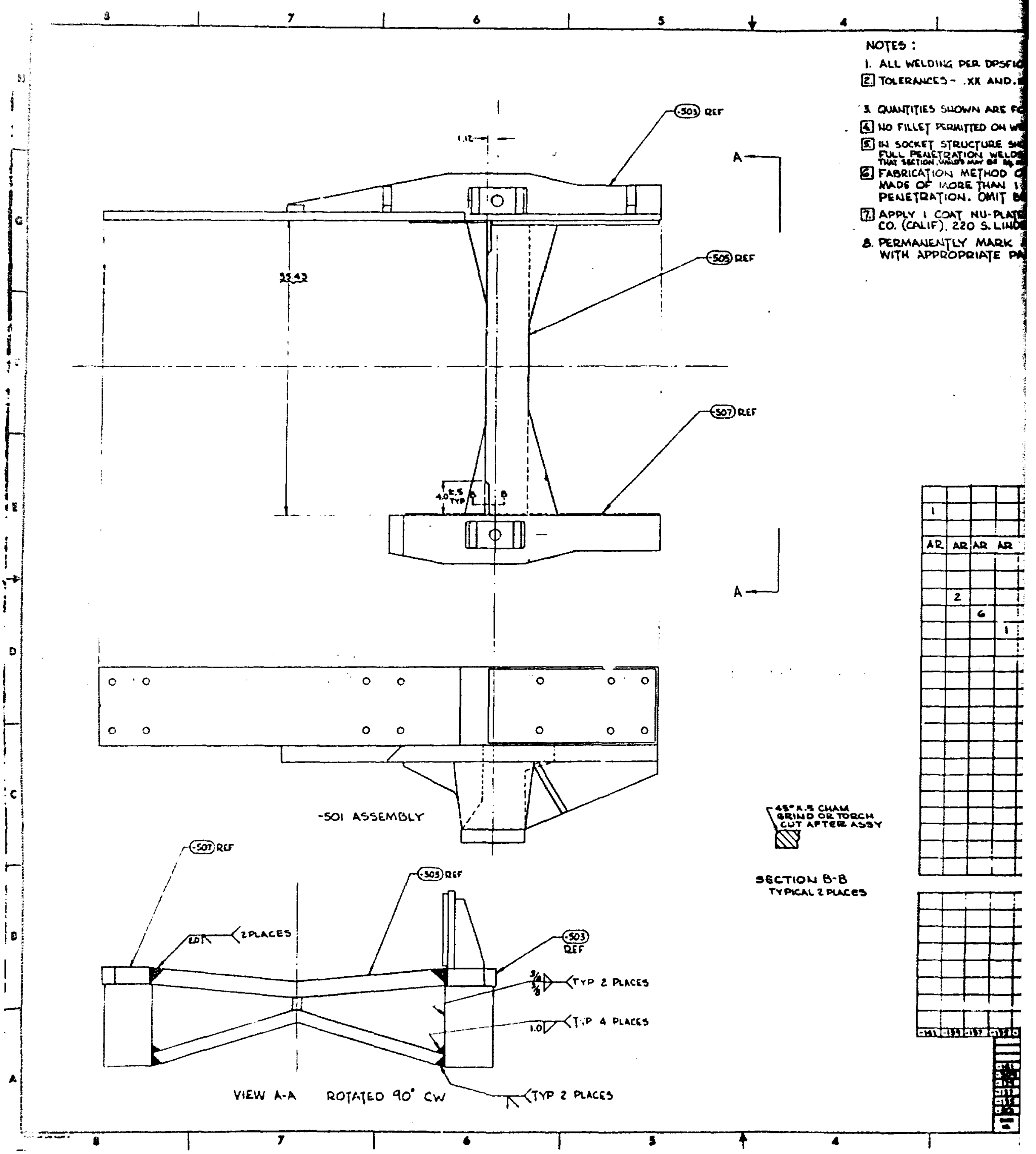
LIST OF MATERIALS OR PARTS LIST

LOCKHEED PROPULSION COMPANY

ROLL OVER PROTECTIVE STRUCTURE

SIZE	CODE IDENT NO	DRAWING NO
E	06491	[illegible]024

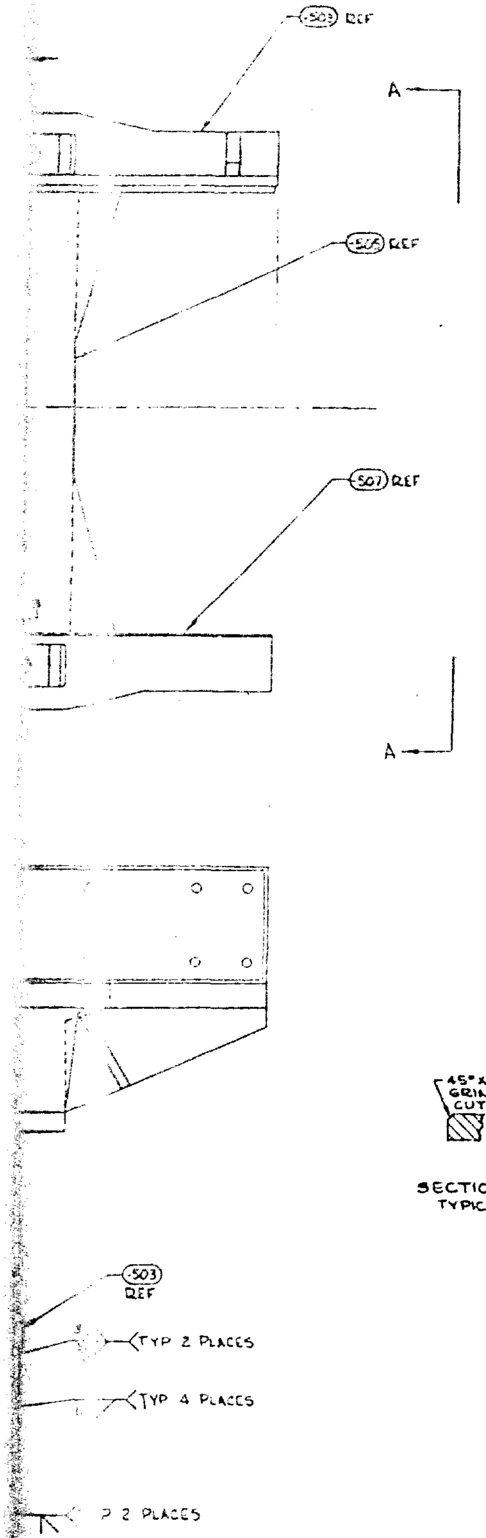
54


NOTES :
1. ALL WELDING PER DPSFI
2. TOLERANCES - .XX AND.
3. QUANTITIES SHOWN ARE F
4. NO FILLET PERMITTED ON W
5. IN SOCKET STRUCTURE SH
FULL PENETRATION WELD
THAT SECTION,
6. FABRICATION METHOD O
MADE OF MORE THAN 1
PENETRATION. OMIT B
7. APPLY 1 COAT NU-PLATE
CO. (CALIF), 220 S. LIND
8. PERMANENTLY MARK
WITH APPROPRIATE PA
-503 REF
-505 REF
-507 REF
1.12
35.43
4.0
2.5 TYP
B
A
-501 ASSEMBLY
45° X .5 CHAM
GRIND OR TORCH
CUT AFTER ASSY
SECTION B-B
TYPICAL 2 PLACES
2 PLACES
TYP 2 PLACES
TYP 4 PLACES
VIEW A-A ROTATED 90° CW
AR

E	D-E, SEE DCN, JOB NO 58C-1007		

NOTES:

1. ALL WELDING PER DPSF100.
2. [2] TOLERANCES - .XX AND .XXX = ± 1/16.
3. QUANTITIES SHOWN ARE FOR 1 ROPS INSTALLATION PER 299279.
4. [4] NO FILLET PERMITTED ON WELD -105 TO -107 IN AREA SHOWN.
5. [5] IN SOCKET STRUCTURE SHOWN, THE 4 VERTICAL WELDS MUST BE FULL PENETRATION WELDS IN THE 8 INCH SECTION SHOWN. ABOVE THAT SECTION, WELDS MAY BE 3/4 IN PENETRATION EXCEPT FOR NOTED FILLET WELDS.
6. [6] FABRICATION METHOD OPTIONAL. PARTS SHOWN MAY BE MADE OF MORE THAN 1 PIECE. WELDS MUST BE FULL PENETRATION. OMIT BEND RADII IF WELDED.
7. [7] APPLY 1 COAT NU-PLATE F PRIMER. INTERNATIONAL PAINT CO. (CALIF), 220 S. LINDEN AVE., SOUTH SAN FRANCISCO, CALIF.
8. PERMANENTLY MARK ASSEMBLIES AND LOOSE PARTS WITH APPROPRIATE PART NO. AND SERIAL NO.



-141	-139	-137	-135	-504	-507	-505	-503	-501 QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE
					1		1			-143	LUG, R .75 X 4.50 X 6.87	STEEL	EMSD103	
1										-141	R-.56 X 8.00 X 37.0	STEEL	EMSD103	
				✓	✓	✓	✓	✓			WELDING		DPSF100	
AR	AR	AR	AR	AR				AR		NU-PLATE F	PRIMER [7]			
	2									-139	R-1.00 X 3.00 X 6.75	STEEL	EMSD103	
		6								-137	R-1.00 X 7.00 X 6.75			
			1							-135	R-.56 X 8.00 X 37.00			
					1					-133	R-2.00 X 5.75 X 31.63			
				1						-131	R-2.00 X 4.50 X 11.50			
						2				-129	R-1.00 X 1.38 X 2.12			
						1				-127	R-.75 X 8.12 X 34.75			
						1				-125	R-1.50 X 8.50 X 36.37 [6]			
						1				-123	R-2.00 X 8.50 X 35.50 [6]			
				1			1			-121	R-.56 X 8.62 X 19.75			
				1			1			-119	R-1.00 X 2.00 X 8.12			
				1			1			-117	R-1.00 X 3.25 X 8.12			
				1			1			-115	R-1.00 X 3.50 X 8.12			
					1		1			-113	R-1.50 X 5.50 X 7.50			
					1		1			-111	R-1.50 X 8.25 X 9.50			
					2		2			-109	R-1.50 X 3.00 8.25			
					1		1			-107	R-1.0 X 8.25 X 30.0			
							1			-105	R-2.00 X 5.75 X 43.38			
				1			1			-103	R-1.00 X 9.12 X 42.75			
				1			1			-101	R-.75 X 9.12 X 23.25	STEEL	EMSD103	
								1		-507	SUBASSEMBLY			
								1		-505				
								1		-503	SUBASSEMBLY			

299239 E

LIST OF MATERIALS OR PARTS LIST

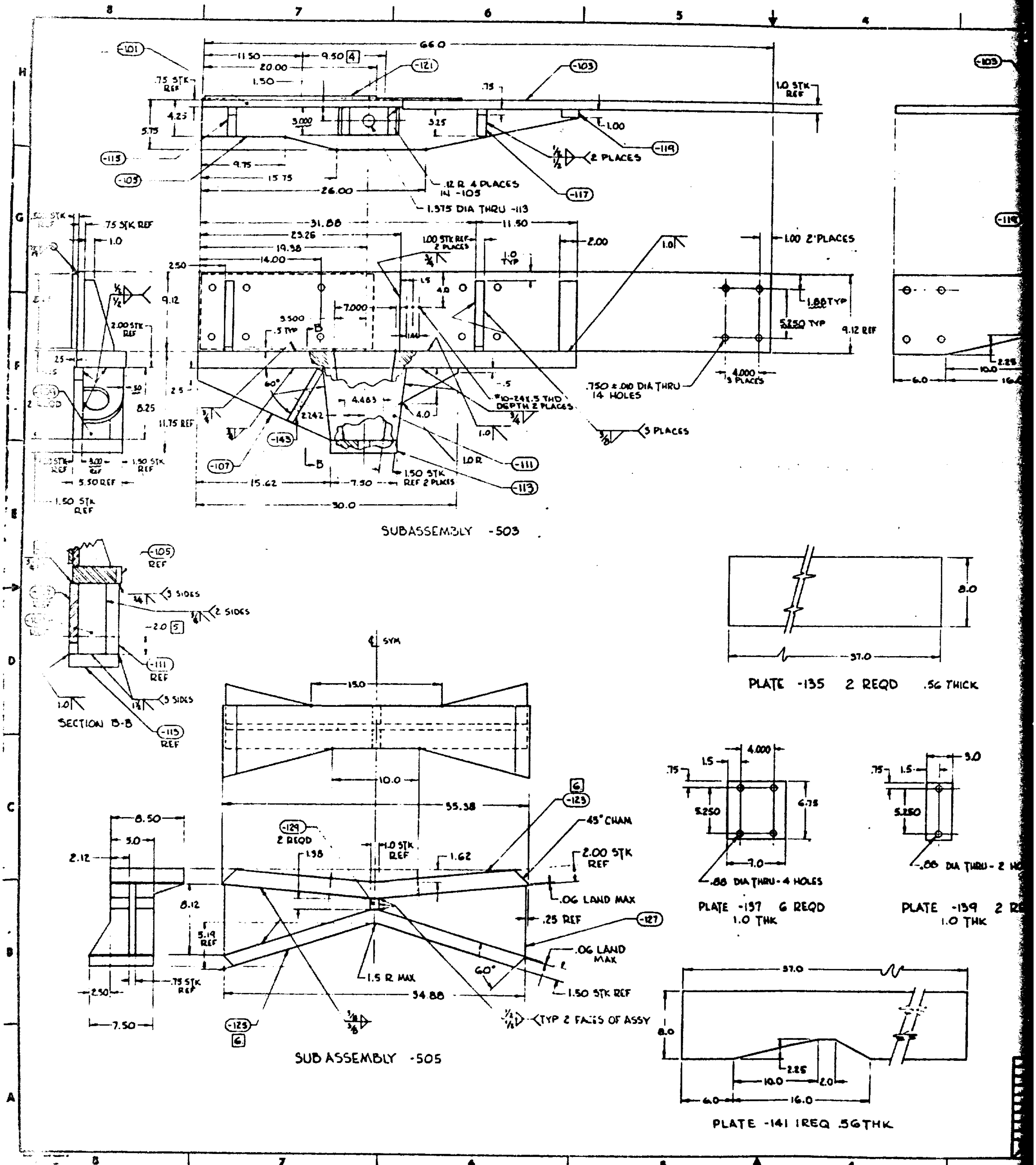
	NEXT ASSY	USED ON
-141	299279	58C-45
-504	299279	58C-45
-139	"	"
-137	"	"
-135	"	"
-501	"	"

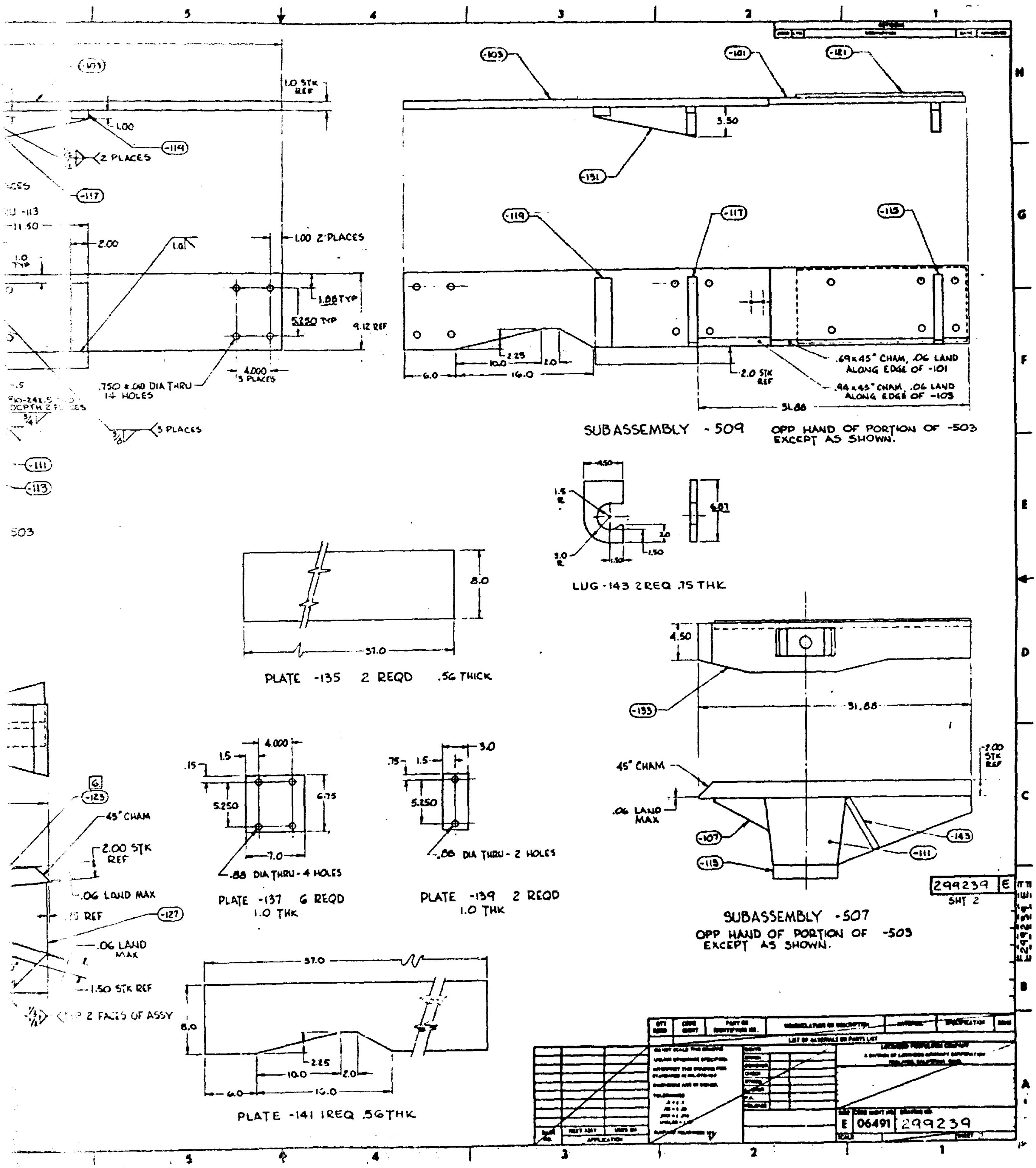
ATTACHMENT STRUCTURE
ROPS BOLT-ON SYSTEM
GK FORKLIFT

E 06491 299239

2 FORM 4

55

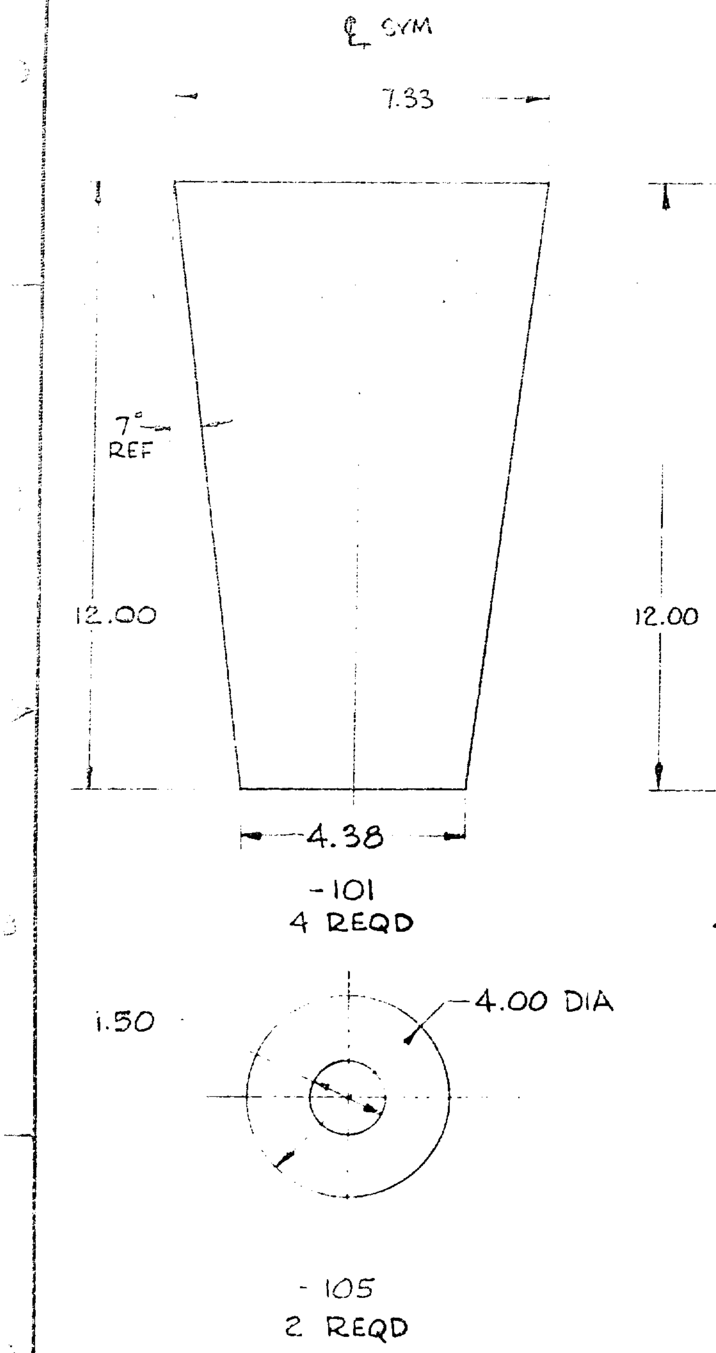

SUBASSEMBLY -503
SECTION B-B
SUB ASSEMBLY -505
PLATE -135 2 REQD .56 THICK
PLATE -137 6 REQD 1.0 THK
PLATE -139 2 R
1.0 THK
PLATE -141 1 REQ .56 THK
.750 ± .010 DIA THRU 14 HOLES
1.575 DIA THRU -113
.12 R 4 PLACES IN -105
#10-24 X .5 THD DEPTH 2 PLACES
.88 DIA THRU - 4 HOLES
45° CHAM
.06 LAND MAX
TYP 2 FACES OF ASSY


SUBASSEMBLY -509 OPP HAND OF PORTION OF -503 EXCEPT AS SHOWN.
.69x45° CHAM, .06 LAND ALONG EDGE OF -101
.94x45° CHAM, .06 LAND ALONG EDGE OF -103
.750 ±.010 DIA THRU 14 HOLES
3 PLACES
2 PLACES
LUG -143 2REQ .75 THK
PLATE -135 2 REQD .56 THICK
PLATE -137 6 REQD 1.0 THK
.88 DIA THRU - 4 HOLES
PLATE -139 2 REQD 1.0 THK
.88 DIA THRU - 2 HOLES
SUBASSEMBLY -507
OPP HAND OF PORTION OF -503 EXCEPT AS SHOWN.
45° CHAM
.06 LAND MAX
2.00 STK REF
1.50 STK REF
2 FACES OF ASSY
PLATE -141 1REQ .56THK
299239 E
SHT 2
E 06491 299239

4 | 3 | 2

NOTES

1. PERMANENT INK MARK EACH PAD WITH APPROPRIATE PART NO.
2. PARTS IN QUANTITIES SHOWN COMPRISE (1) KIT USED IN THE INSTALLATION OF ROPS PER DWG 299279.
3. BAG & TAG EACH KIT. PERMANENT MARK TAG WITH NUMBER 299029-501.



✓			INS
2	73015	-105	WAS
4	73015	-103	PA
4	73015	-101	PA
QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	
-501			

-501	299279	FINAL
DASH NO.	NEXT ASSY	USED ON
	APPLICATION	

DO NOT SCALE THIS DRAWING

UNLESS OTHERWISE SPECIFIED:

INTERPRET THIS DRAWING PER STANDARDS IN MIL-STD-100

DIMENSIONS ARE IN INCHES.

TOLERANCES
.X = ± .1
.XX = ± .03
.XXX = ± .010
ANGLES = ± 30'

SURFACE ROUGHNESS 125

CONTR DAAK
DRAWN
DESIGNER
CHECK
STRESS
ENGR
P.A.
RELEASE

4 | 3 | 2

3 2 1

NOTES

1. PERMANENT INK MARK EACH PAD WITH APPROPRIATE PART NO.
2. PARTS IN QUANTITIES SHOWN COMPRISE (1) KIT USED IN THE INSTALLATION OF ROPS PER DWG 299279.
3. BAG & TAG EACH KIT. PERMANENT MARK TAG WITH NUMBER 299029-501.

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

D

C

299029

B

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE
✓			INSTALLATION		SERVICE BULLETIN 112	
2	73015	-105	WASHER~ .125 THK NOM	FABREEKA		
4	73015	-103	PAD			
4	73015	-101	PAD			

-501 LIST OF MATERIALS OR PARTS LIST

NEXT ASSY	USED ON
299279	FINAL

APPLICATION

DO NOT SCALE THIS DRAWING

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INTERPRET THIS DRAWING PER STANDARDS IN MIL-STD-100
DIMENSIONS ARE IN INCHES.
TOLERANCES
.X = ± .1
.XX = ± .03
.XXX = ± .010
ANGLES = ± 30'
SURFACE ROUGHNESS 125

CONTR	DAAK02-72-C-0574	
DRAWN	11/13/73	H.M. POLAND
DESIGNER	11/13/73	
CHECK	11/13/73	
STRESS	11/13/73	
L. ENGR	11-14-73	
P.A.		
RELEASE	11-14-73	

LOCKHEED PROPULSION COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
REDLANDS, CALIFORNIA 92373

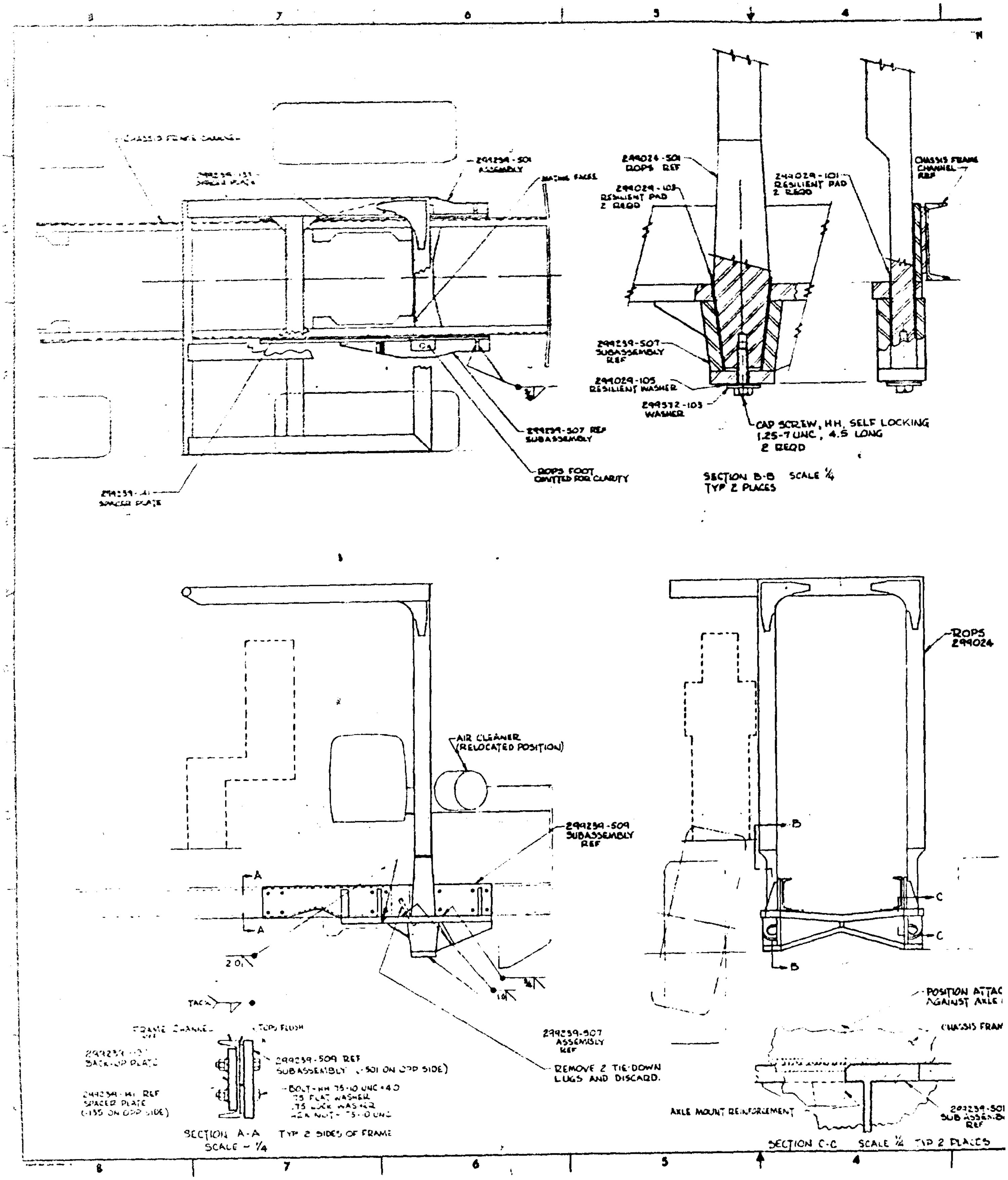
KIT OF RESILIENT PADS FOR ROPS FOR 6K FORKLIFT

A

SIZE	CODE IDENT NO.	DRAWING NO.
C	06491	299029

SCALE 1/2 SHEET 1 OF 1

2 FORM 4 1 MPO 684 - 58C-1007



CHASSIS FRAME CHANNEL
299239-501 ASSEMBLY
MATING FACES
299239-507 REF SUBASSEMBLY
ROPS FOOT OMITTED FOR CLARITY
299239-41 SPACER PLATE
299024-501 ROPS REF
299029-103 RESILIENT PAD 2 REQD
299029-101 RESILIENT PAD 2 REQD
CHASSIS FRAME CHANNEL REF
299239-507 SUBASSEMBLY REF
299029-105 RESILIENT WASHER
299572-103 WASHER
CAP SCREW, HH, SELF LOCKING 1.25-7 UNC, 4.5 LONG 2 REQD
SECTION B-B SCALE 1/4 TYP 2 PLACES
AIR CLEANER (RELOCATED POSITION)
299239-509 SUBASSEMBLY REF
ROPS 299024
TACK
299239-507 ASSEMBLY REF
REMOVE 2 TIE-DOWN LUGS AND DISCARD.
299239-509 REF SUBASSEMBLY (-501 ON OPP SIDE)
SECTION A-A TYP 2 SIDES OF FRAME
SCALE - 1/4
POSITION ATTAC AGAINST AXLE
CHASSIS FRAN
AXLE MOUNT REINFORCEMENT
299239-501 SUB ASSEMBLY REF
SECTION C-C SCALE 1/4 TYP 2 PLACES

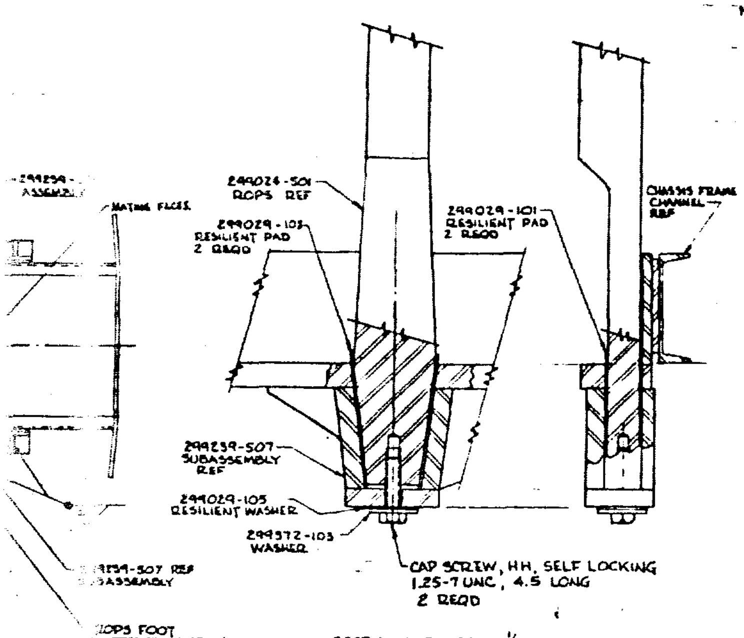
NOTES:

1. ALL WELDING PER DPSF100.

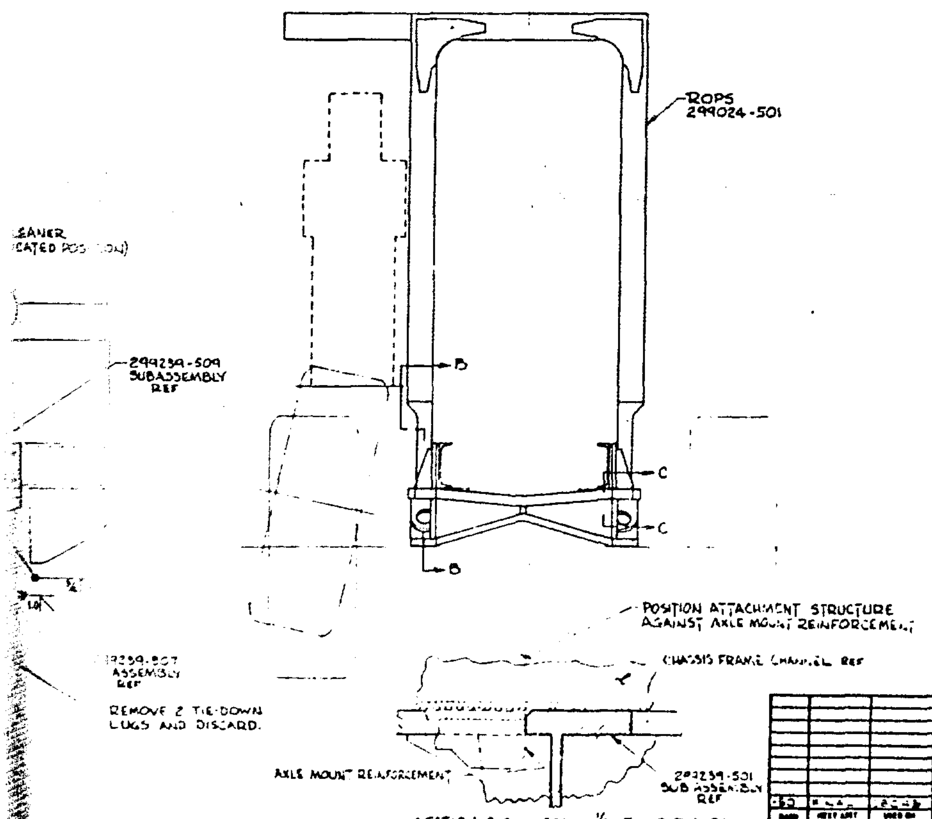
$\boxed{2}$ INSTALL ROPS ON FORKLIFT TRUCK PER SERVICE BULLETIN 112. QUANTITIES ARE CALLED OUT IN BULLETIN.

$\boxed{3}$ PARTS 299572-107 & -109 ARE NOT SHOWN ON F/D. THEY ARE SHOWN IN SERVICE BULLETIN 112.

	A	(1-14) SEE DCN A		



SECTION B-B SCALE ¼
TYP 2 PLACES



SECTION C-C SCALE ¼ TYP 2 PLACES

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
✓			INSTALLATION	$\boxed{2}$ $\boxed{3}$	SERVICE BULLETIN 112
AR	94499	MOLYKOTE	LUBRICANT		
✓			WELDING		DPSF100
✓	03038		CAP SCR HH SELF-LOCKING 1.25-7 UNC 4.5 LONG	STEEL SAE GRADE 8	MIL-F-18240
✓			LOCKWASHER .75 SPRING	STEEL $\boxed{2}$	
✓			WASHER -.75 FLAT MED	STEEL $\boxed{2}$	
✓			HEX NUT-.75-10 UNC SAE GR 8	STEEL $\boxed{2}$	
✓			BOLT HH-.75-10 UNC, 4.0 LONG SAE GRADE 8	STEEL $\boxed{2}$	
✓		299259-509	ATTACHMENT STRUCTURE SUB ASSEMBLY	$\boxed{2}$	
✓		299259-501	ATTACHMENT STRUCTURE ASSEMBLY		
✓		299259-141	PLATE-SPACER		
✓		299259-139	PLATE-BACK-UP		
✓		299259-137	PLATE-BACK-UP		
✓		299259-135	PLATE-SPACER	$\boxed{2}$	
✓		299029-101	PAD, RESILIENT (KIT)	$\boxed{2}$	
✓		299029-103	PAD RESILIENT (KIT)		
✓		299029-105	WASHER, RESILIENT (KIT)		
✓		299572-09	BEVEL NUT $\boxed{3}$	$\boxed{2}$	
✓		299572-107	SPACER BLOCK $\boxed{3}$	$\boxed{2}$	
✓		299572-103	WASHER	$\boxed{2}$	
✓		299024-501	ROLLOVER PROTECT STRUCT		

299279 A

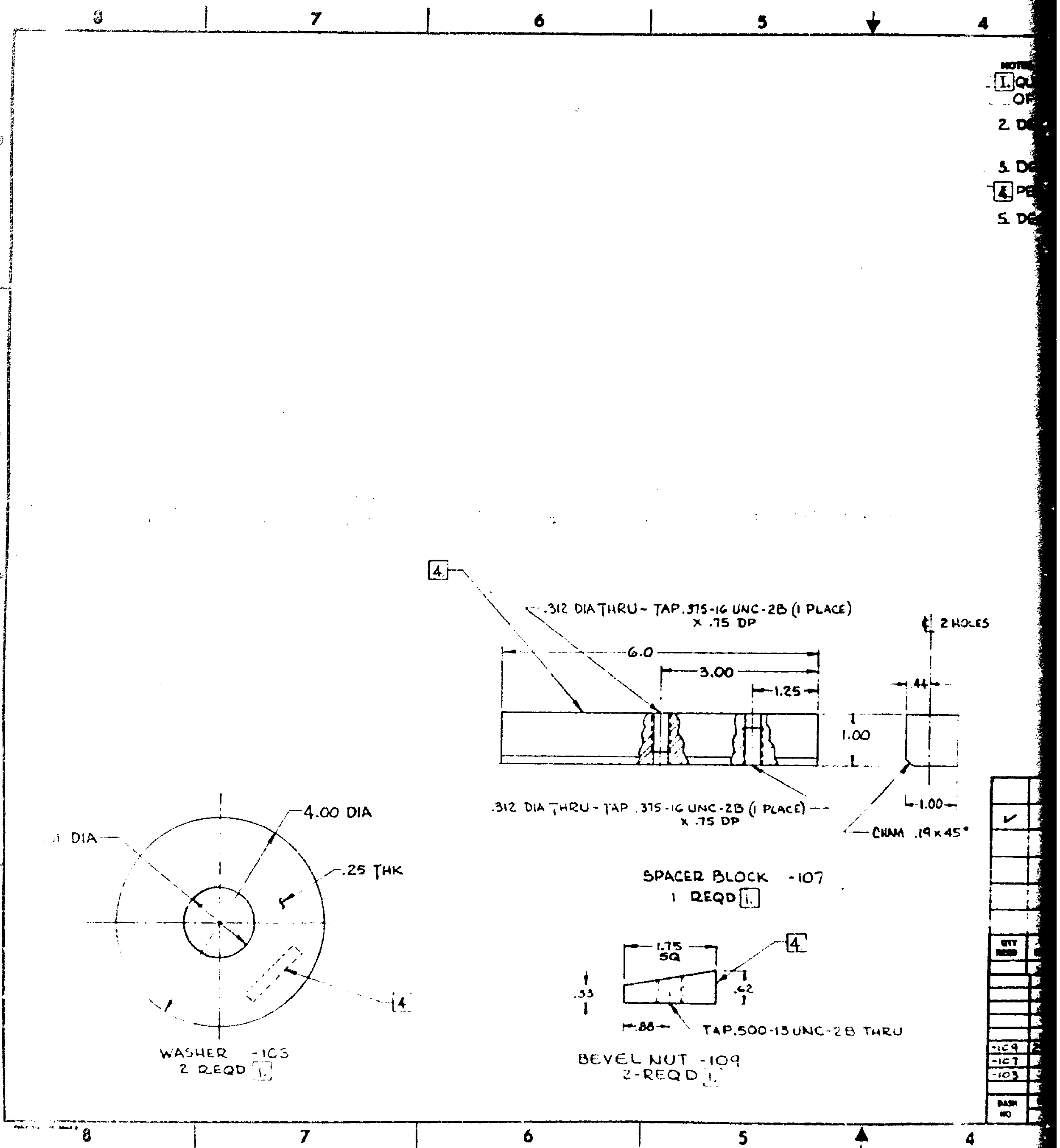
LIST OF MATERIALS OR PARTS LIST

ROPS INSTALLATION
BOLT-ON SYSTEM
FORKLIFT

E 06491 299279

FORM 4

58

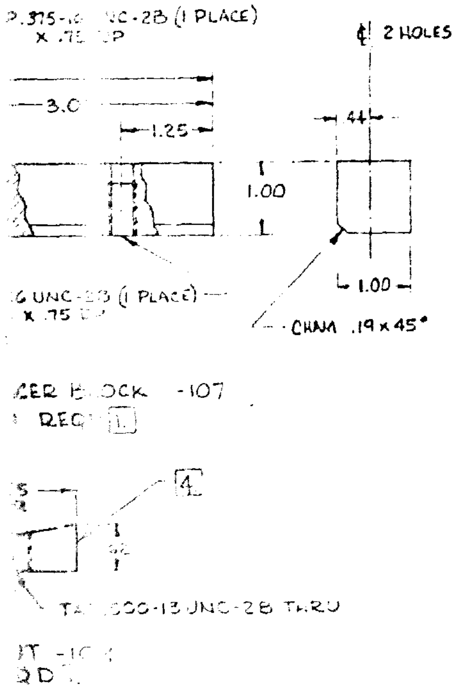


8
7
6
5
4
NOTES
1. QU
OF
2. DE
3. DE
4. PE
5. DE
4.
.312 DIA THRU - TAP .375-16 UNC-2B (1 PLACE) X .75 DP
℄ 2 HOLES
6.0
3.00
1.25
.44
1.00
.312 DIA THRU - TAP .375-16 UNC-2B (1 PLACE) X .75 DP
1.00
CHAM .19 x 45°
SPACER BLOCK -107
1 REQD 1.
4.00 DIA
DIA
.25 THK
4
WASHER -103
2 REQD 1.
1.75 SQ
4
.33
.62
.88
TAP .500-13 UNC-2B THRU
BEVEL NUT -109
2-REQD 1.
QTY REQD
-109
-107
-103
DASH NO

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	(1-10) SEE DCN "A" JOB 58C-1007	[illegible]	[illegible]

NOTES.

1. QUANTITIES SHOWN ARE FOR ATTACHMENT OF 1 ROPS UNIT. SEE SERVICE BULLETIN 112
2. DELETED
3. DELETED
4. PERMANENT MARK WITH APPLICABLE PART NO.
5. DELETED



QTY REQD	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	DRAWING OR DOCUMENT NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	ZONE	ITEM NO.
✓					ASSEMBLY PROCEDURE 1.		SERVICE BULLETIN 112		
			-109		BEVEL NUT	STEEL	ASTM A-36		
			-107		SPACER BLOCK	STEEL	ASTM A-36		
			-103		WASHER	STEEL	ASTM A36		

LIST OF MATERIALS OR PARTS LIST

DASH NO	NEXT ASSY	USED ON
-109	299279	[illegible]
-107	"	"
-103	"	"

APPLICATION

DO NOT SCALE THIS DRAWING

UNLESS OTHERWISE SPECIFIED

INTERPRET THIS DRAWING PER STANDARDS IN MIL-STD-100

DIMENSIONS ARE IN INCHES.

TOLERANCES

.X ± .1

.XX ± .03

.XXX ± .010

ANGLES ± 0° 30'

SURFACE ROUGHNESS 125 ✓

CONTR DAAK02-72-C-0574

DRAWN [illegible] [illegible]

DESIGNER [illegible]

CHECK [illegible]

STRESS [illegible]

L. ENGR [illegible]

P.A.

RELEASE [illegible]

LOCKHEED PROPULSION COMPANY

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

REDLANDS, CALIFORNIA 92373

ROPS ATTACHMENT PARTS FOR GK FORKLIFT

SIZE D | CODE IDENT NO 06491 | DRAWING NO. 299572

SCALE [illegible] | SHEET [illegible]

FORM 4 | MPO 684 | 58C-1007

299572 A

59

5.2.1.4 ROPS Assembly

The assembly of the ROPS, sockets and chassis reinforcements mounted on the forklift is shown on LPC Drawing No. 299279, Revision A, 6K Forklift Bolt-On System ROPS Installation, Figure 34a. The details of assembly procedure are specified in Service Bulletin 112 called out as Note 2 of the drawing. Additional detail parts required for ROPS installation and called out on Drawing No. 299279A are shown in LPC Drawing No. 299572, Revision A, ROPS Attachment Parts for 6K Forklift, Figure 34b.

5.2.2 Structural Analysis

5.2.2.1 Analysis Approach

The method of analysis used was identical to the method used on the development unit except additional analysis was performed for an actual rollover condition. This was done because the bolted-on (prototype) unit develops higher stresses in the forklift chassis than the development weld-on design. To perform this analysis the vehicle mass was assumed to be concentrated at two locations. The C.G. of one of the mass segments was located in the center of the aft vehicle structure and the other was located at the center of the forward structure 70 inches forward of the ROPS socket. Then the frame was analyzed for a total side load equal to the SAE required side load of 15,000 lbs applied to these C.G. locations and reacted at the ROPS socket location. The resulting frame stresses exceeded the yield strength of the forklift frame. However, since frame yielding was felt to provide an additional source for developing energy and clearance and installation problems would be encountered with larger reinforcements, the reinforcement size was maintained and the frame was allowed to yield.

5.2.2.2 Analysis Results

The predicted ROPS side load vs. deflection curve is shown in Figure 35. The long foot design did not significantly change the elastic stiffness of the structure. Therefore the elastic and transition section of the curve is based on the development unit test data. Since the long foot design changes the plastic hinge location, the ultimate capability was recomputed and reduced by an actuator rotation factor. The ultimate capability was then given a load range to account for material strength variation and added to the curve.

The predicted ROPS vertical load vs. deflection is shown in Figure 36 and is based on the development unit test data.

The structural analysis of the unit is given in Section 6.5 of the Appendix and a summary of the results is shown in Tables 5, 6, and 7. Table 5 is identical to Table 1 except ratioed for a slightly higher expected maximum side load, P_1 of 33,300 lbs.

Table 6 is a summary of frame stresses. Location 1 is a check of weld shear between the socket vertical plates and bottom plate. Point 2 is a check of the outboard area of the socket shearing out due to a right hand side load. Note

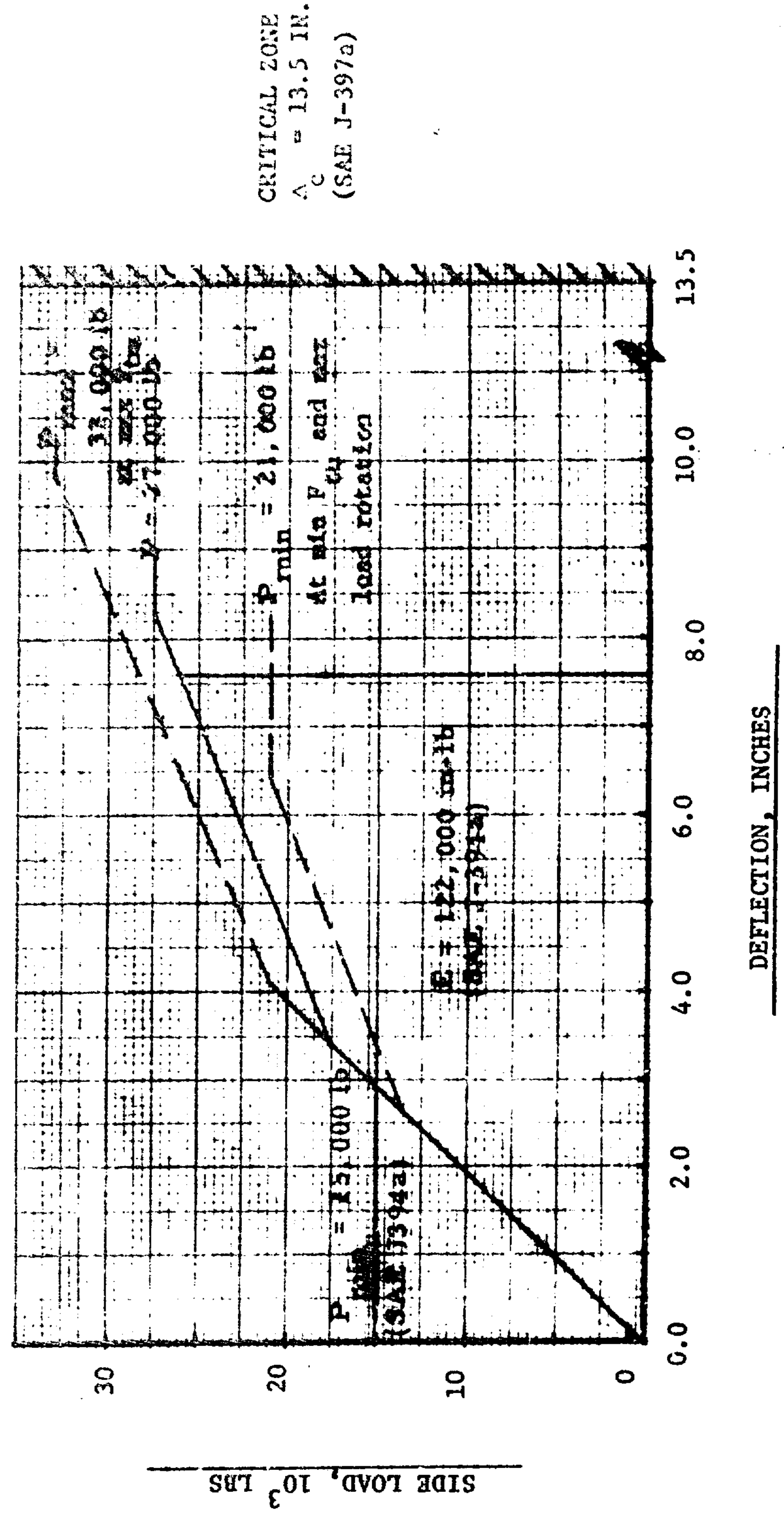


Figure 35 - Predicted ROPS Side Load Deflection and Energy Absorption

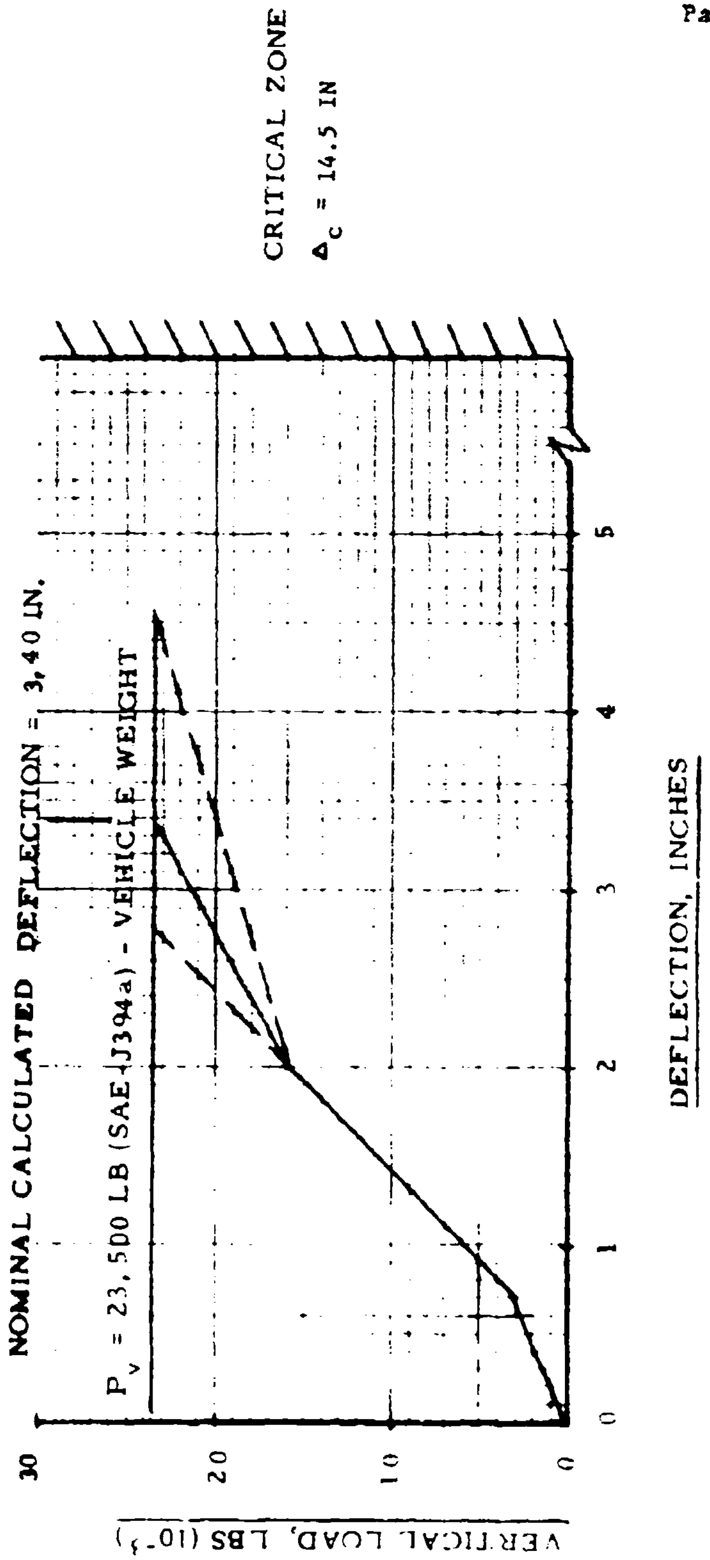
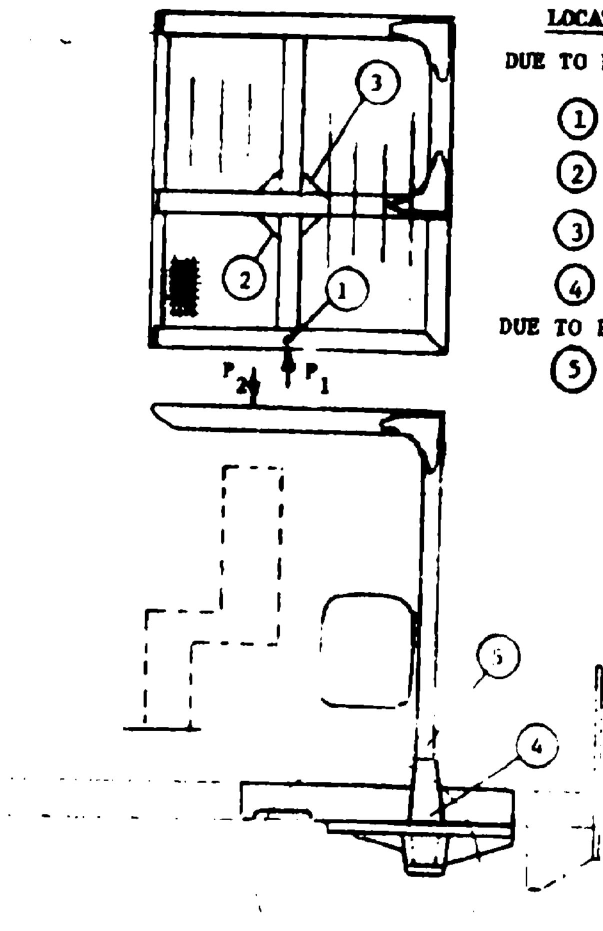


Figure 36 - Predicted ROPS Vertical Load Deflection



LOCATION		STRESS	ALLOWABLE	F.S.
DUE TO P_1	=	33,300 lbs		
1		16,700 lbs (col)	38,000 lbs (col)	2.28
2		16,200 psi	38,000 F_{ty}	2.34
3		7,100 psi	38,000 F_{ty}	High
4		152,000 psi	183,000 F_{bu}	1.20
DUE TO P_2	=	23,500 lbs		
5		49,000 psi	57,000 F_{by}	1.16

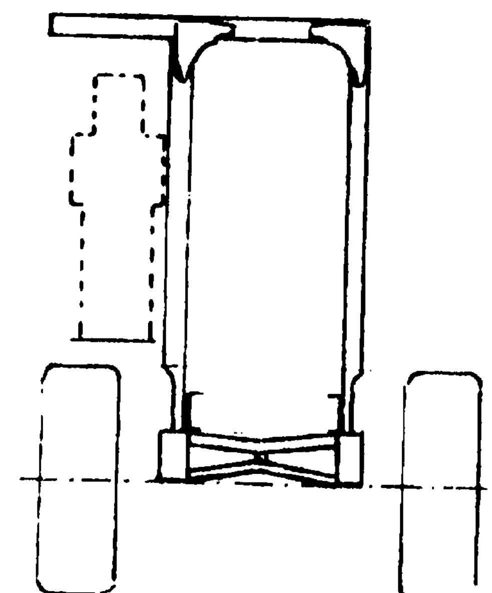


Table 5 - ROPS Stress Summary

DUE TO ROPS SIDE LOAD = 33,300 LBS:

Location	Stress	Allowable	F.S.
1	f_s = 37,000 psi	45 ksi F_{su}	1.22
2	f_s = 41,000 psi (rollover)	45 ksi F_{su}	1.10
2	f_s = 24,000 psi	45 ksi F_{su}	1.84
3	f_b = 38,000 psi	48 ksi F_{by}	1.26
4	f_t = 29.000 psi	38 ksi F_{ty}	1.30
5	f_t = 32,500 psi	38 ksi F_{ty}	1.17

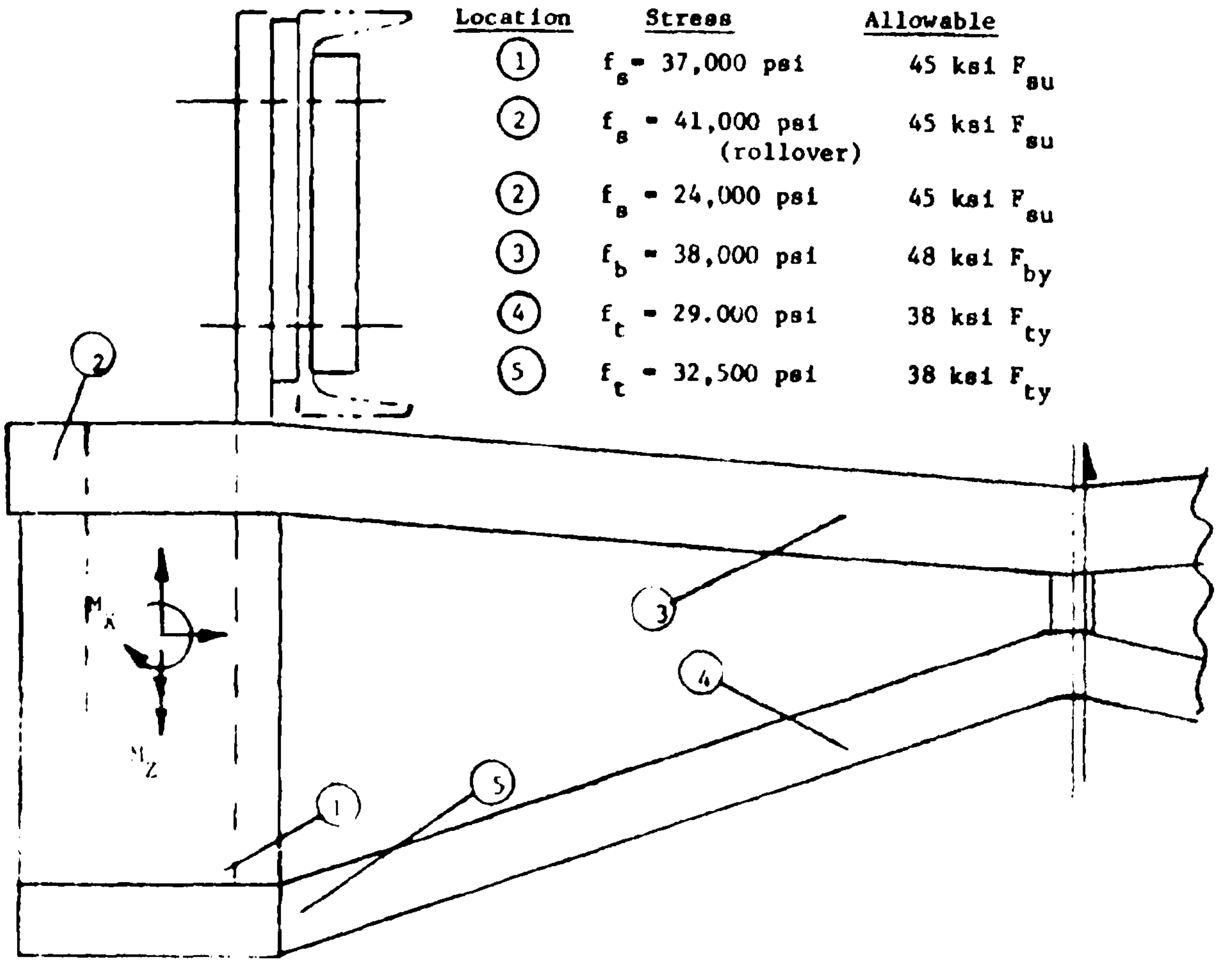


Table 6 - Frame Stress Summary

LOCATION	STRESS	ALLOWABLE	F.S.
1	f_b = 102,000 PSI (ROLLOVER)	105 KSI F_{bu}	1.03
2	f_b = 23,000 PSI (ROLLOVER)	48 KSI F_{by}	2.10
3	f_c = 20,700 PSI	24 KSI F_{cc}	1.16
4	f_{br} = 64,000 PSI (ROLLOVER)	90 KSI F_{bru}	1.40
5 FRAME	f_b = 90,000 PSI (ROLLOVER)	105 KSI F_{bu}	1.17
6 FRAME	f_b = 26,000 PSI (ROLLOVER)	70 KSI F_{tu}	2.70
7 PLATE	f_b = 7,600 PSI (ROLLOVER)	38 KSI F_{ty}	HIGH

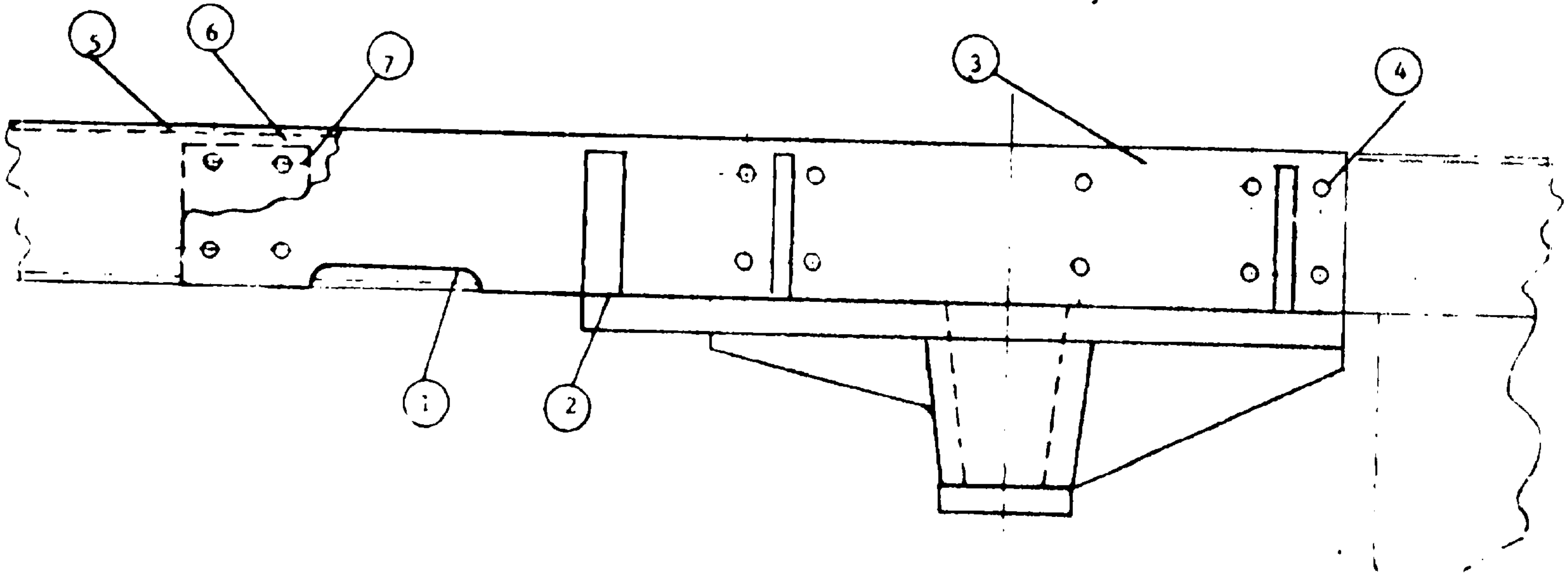


Table 7 - Frame Stress Summary (Cont'd)

that for an actual rollover, the side load may be applied in line with the ROPS vertical legs. The ROPS then can develop more side load capability and make the socket more critical. Locations 3, 4, 5 are crossbeam bending stress checks for the ROPS lower fixity moments, M_x and M_z.

Table 7 is a summary of stresses due to frame bending moments. Points 1 through 3 are local bending checks, point 4 is a hole bearing check at the highest bolt load location. Location 5 through 7 are additional local bending checks. Location 1 is a rollover check of the forklift frame and reinforcement jointly carrying the SAE required side load of 15,000 lbs. Location 5 is a check of the frame at the edge of the reinforcement for the same condition. The stress levels of 102,000 psi and 90,000 psi are predicting yielding at these two points. The rollover test conducted on this unit 11 October 73 did produce yielding at these two locations. Therefore, the magnitude of the SAE required side load appears to be similar to that experienced in the rollover test.

5.2.2.3 Comparison with Test Results

A comparison of predicted side load to test side load is shown in Figure 37. A comparison of predicted vertical load to test vertical load is shown in Figure 38. A thorough discussion comparing predicted loads to test loads is given in Section 6.7, "Analysis of Prototype Test Results". In summary, the vertical load prediction is felt to be sufficiently accurate. The change in socket design from the development unit did not affect severely foot rotation in the socket. Therefore the vertical load prediction based on the development test was accurate.

The change in socket design did, however, greatly affect foot <u>twisting</u> in the socket which produced a sag in the curve and made the elastic curve softer than expected. The error was predicting an elastic curve based on the 6K development test instead of basing the elastic curve on the caterpillar bedplate test which utilized a similar socket design. Ultimate capability developed in the test was in the middle of the predicted range.

Analysis of the prototype test results shows that not only the non-linear fixity mechanism for rotation, discussed in Section 5.1.2.2, is required, but a non-linear fixity mechanism for foot twisting is required for a computer model of ROPS structures with sockets. These points, it is felt, demonstrate the difficulty in predicting the ROPS elastic curve for ROPS designs with sockets.

A review of the strain gage data indicates material yielding only in the ROPS vertical tubes and in the ROPS gussets at the upper end of the vertical tubes. Assuming ROPS tube $F_{TY} = 55{,}000$ psi,

$$\epsilon \text{ P.L.} = \frac{F_{TY}}{E} = \frac{55000}{29 \times 10^6} = 1900\mu \text{ in/in}$$

$$\epsilon \text{ Yield} = 1900\mu \text{ in/in} + 2000\mu \text{ in/in} = 3900\mu \text{ in/in}$$

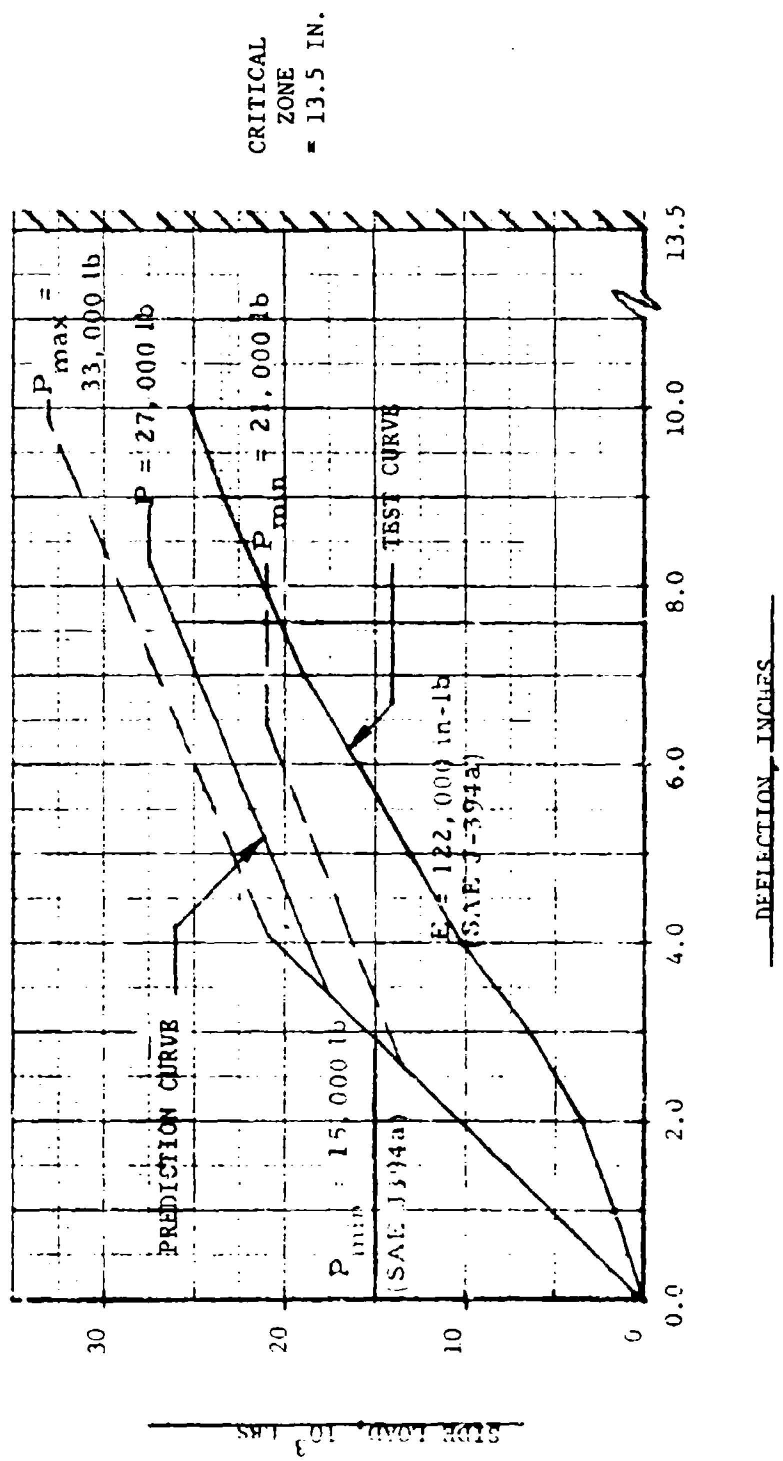


Figure 37 - Comparison of ROPS Side Load Deflection to Prediction

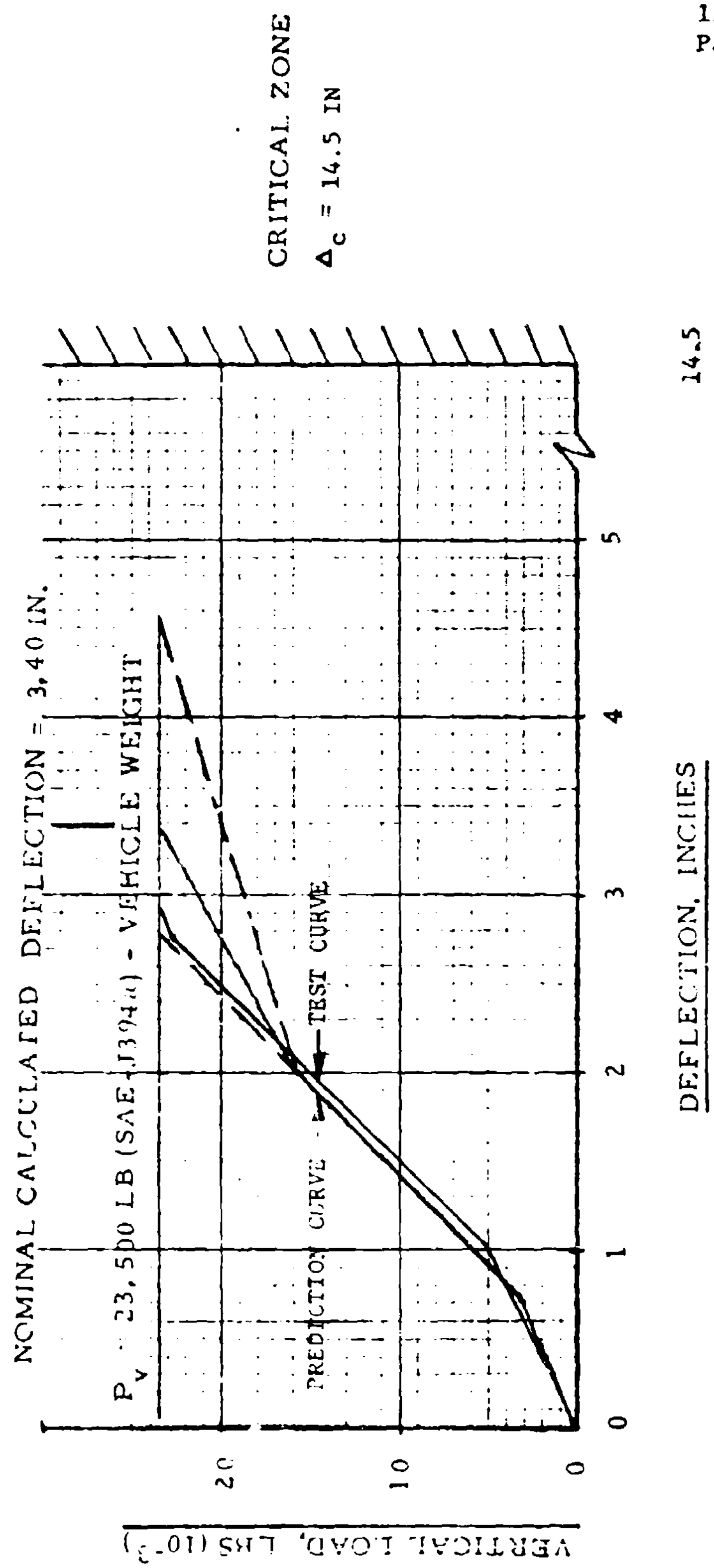


Figure 38 - Comparison of ROPS Vertical Load Deflection to Prediction

At required side load energy, strain gage 1 at 2400 μ in/in exceeded the material proportional limit and strain gage 2 at 3900 μ in/in reached material yield strength.

One of the two strain gages on the gussets recorded the highest strain in the test. At required side load energy, gage 8 and 10 developed 3860 μ in/in and -4750 μ in/in respectively. Assuming ROPS plate F_{TY} = 40,000 psi,

$$\epsilon \text{ P.L.} = \frac{40{,}000}{29 \times 10^6} = 1380\,\mu \text{ in/in}$$

$$\epsilon \text{ Yield} = 1380 + 2000 = 3380\,\mu \text{ in/in}$$

Both gages exceeded material yield strain of 3,380 μ in/in. However, from LPC Specification EMSD103, material elongation at failure is 20% or, 200,000 μ in/in. Therefore, the ROPS structure met required energy at

$$\frac{4750}{200{,}000} \times 100, \text{ or } 2\% \text{ of failure elongation}$$

5.2.3 Fabrication

The Critical Design Review (CDR) for the 6K Prototype ROPS was held by telecon with S. Newman and W. Stewart of MERDC on 23 July 73. Approval was given by MERDC for LPC to proceed with fabrication of the Prototype hardware. Bids were received and the fabrication contract awarded to Tube-Lok Products, Portland, Oregon on 3 August 73 with a scheduled delivery date of 20 August.

During fabrication, a dimensional discrepancy was disclosed on the drawings which would have resulted in a poor fit-up between the canopy and the attachment structure. Since the canopy was built and part of the attachment structure was also completed, it was decided to modify the attach structure dimensions to fit the canopy. The modification would permit installation on the test frame but would not be maintained on the production design because it did not provide latitude for the band of frame variations expected in the field.

5.2.4 Certification Testing

The certification testing for the 6000 lb forklift ROPS consisted of tests to demonstrate compliance with SAE standards for falling object protection, side load force and energy, and vertical load.

5.2.4.2 ROPS Installation for Certification Test

The ROPS and attachment structure were installed to the Type "F" chassis in preparation for certification testing and possible usage during a subsequent roll demonstration test.

Upon receipt of the structure, it was found that the modification made during fabrication to correct the dimensional discrepancy resulted in a skewing of the sockets, and there was interference with the bar through which the rear wheels are attached to the frame.

The bar was ground off to permit installation after it was determined that the material to be removed was not load carrying and removal would not invalidate the test.

During the installation procedure, time for each operation was noted and careful observation was maintained for information to be used in the installation procedures. Other than the interference, no problems developed during installation.

Tie down of the 6K frame for the prototype test differed from the development test. In the latter test, the structure was attached to the test bay floor by tie downs welded to the frame reenforcement structure (see Figure 39). After review of this method with some members of the SAE sub-committee 12 (Vehicle Test Codes) on tour of our facility, it was decided that a more realistic load path would be developed if the axles were attached to the floor and the axles were blocked to the vehicle frame. Figures 40 and 41 show the tie-downs at the rear wheels and Figure 42 shows the conditions at the front wheels.

5.2.4.3 ROPS Certification Test

Static certification testing was performed with the prototype ROPS and reinforcements installed on the Type "F" 6K Forklift on August 28. The tests were witnessed by W. Stewart and S. Newman of USAMERDC. The unit passed successfully all SAE requirements. The testing (in sequence conducted) with significant requirements and results is summarized as follows:

1. A 500-lb weight was dropped 17 feet onto the steel mesh on top of the ROPS in compliance with the FOPS requirements of SAE recommended practice J231. Figure 43 shows the unit in the test bay just prior to dropping the weight for the FOPS test. The weight did not penetrate the top of the critical zone (SAE Recommended Practice J297a) 14.5 inches below the mesh. The structure deflected 6.18 inches upon impact of the weight as measured from the high speed movies. Post-test examination disclosed a small crack in the weld of one of the screen bars, and a deformation of 1.34 inches of the screen. Figure 44 shows the screen after impact.

2. A test was conducted to show compliance with the 15,000 lb side load and 122,000 in-lb side load energy requirements of SAE Recommended Practice J394a.

Figure 45 shows the load deflection curve for the side loading condition and indicates the structural adequacy for both the side load and energy requirements. The slope of the deflection curve indicates a softer system than had

Figure 39 - Development Test Tie-Down

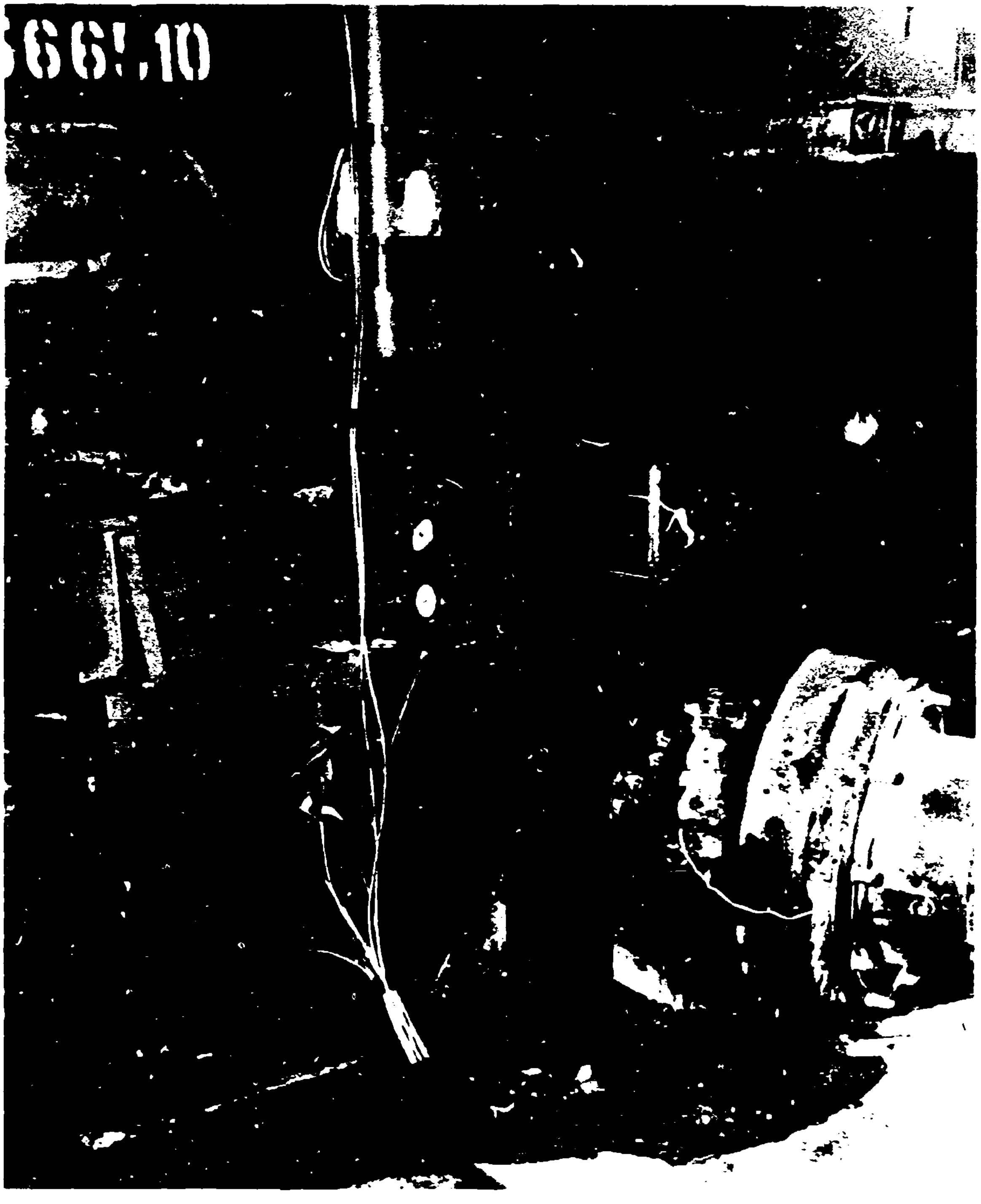


Figure 40 - Prototype Test Rear Wheel Tie Down

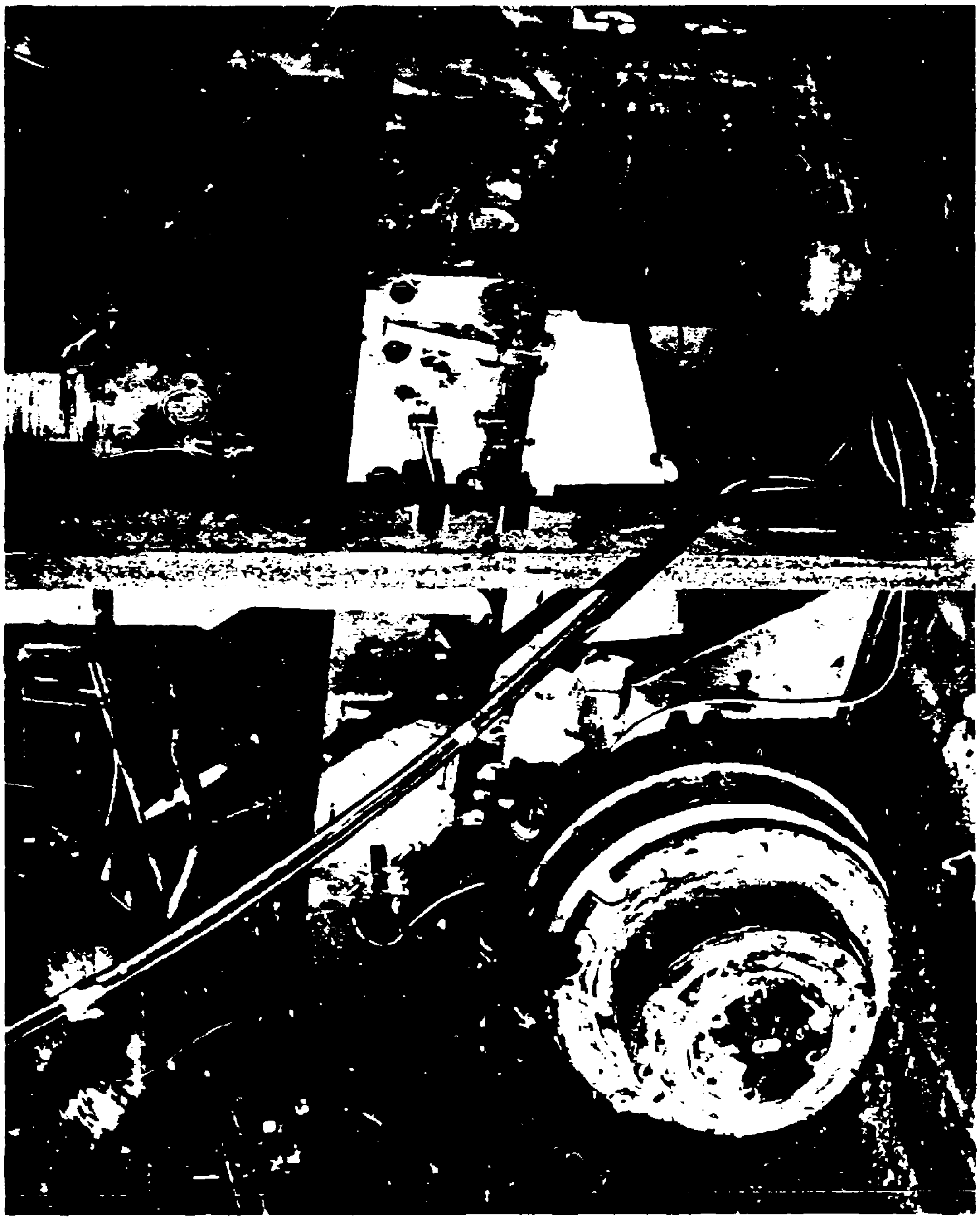


Figure 41 - Prototype Test Rear Wheel Tie Down

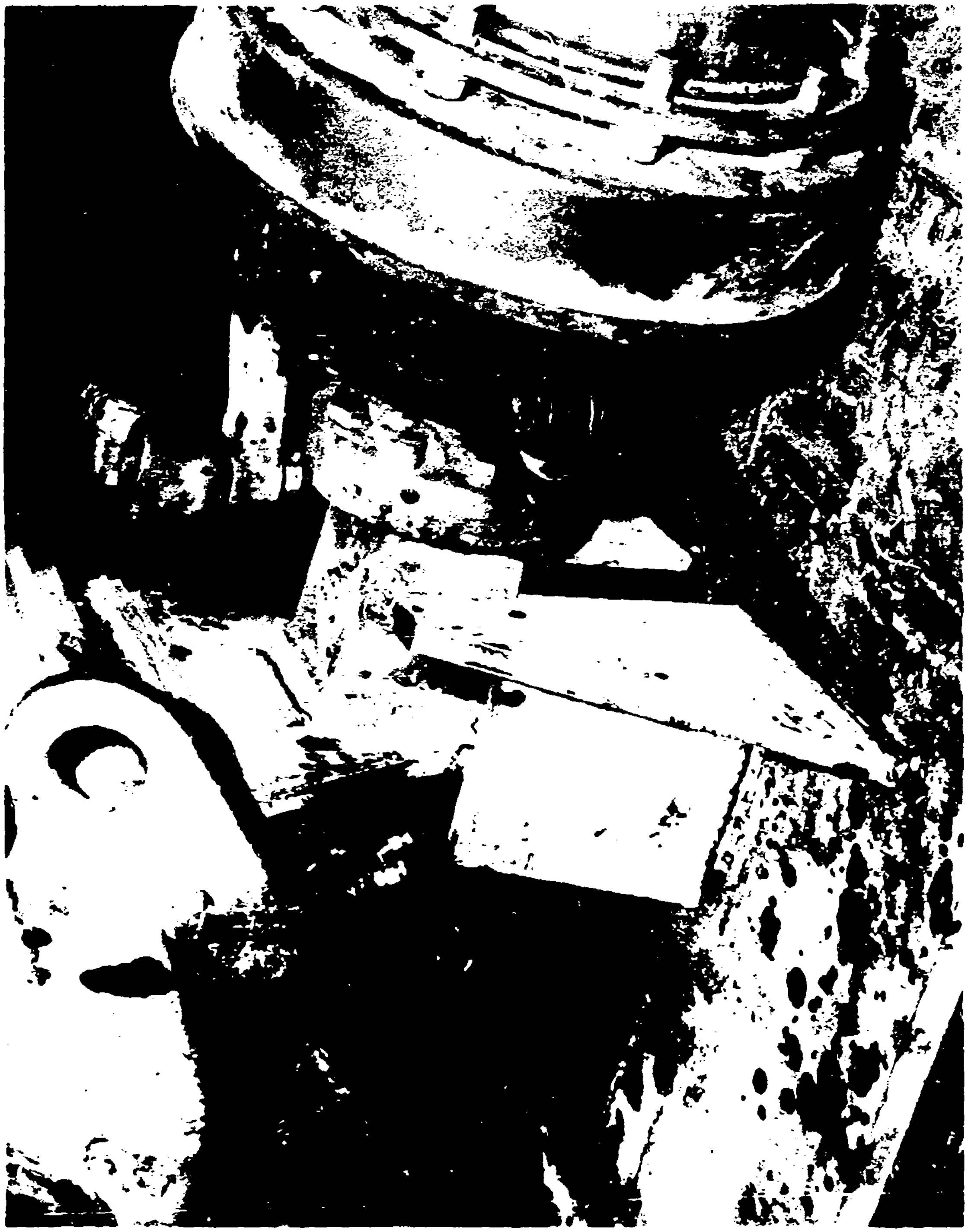


Figure 42 - Prototype Test Front Wheel Tie Down

10321

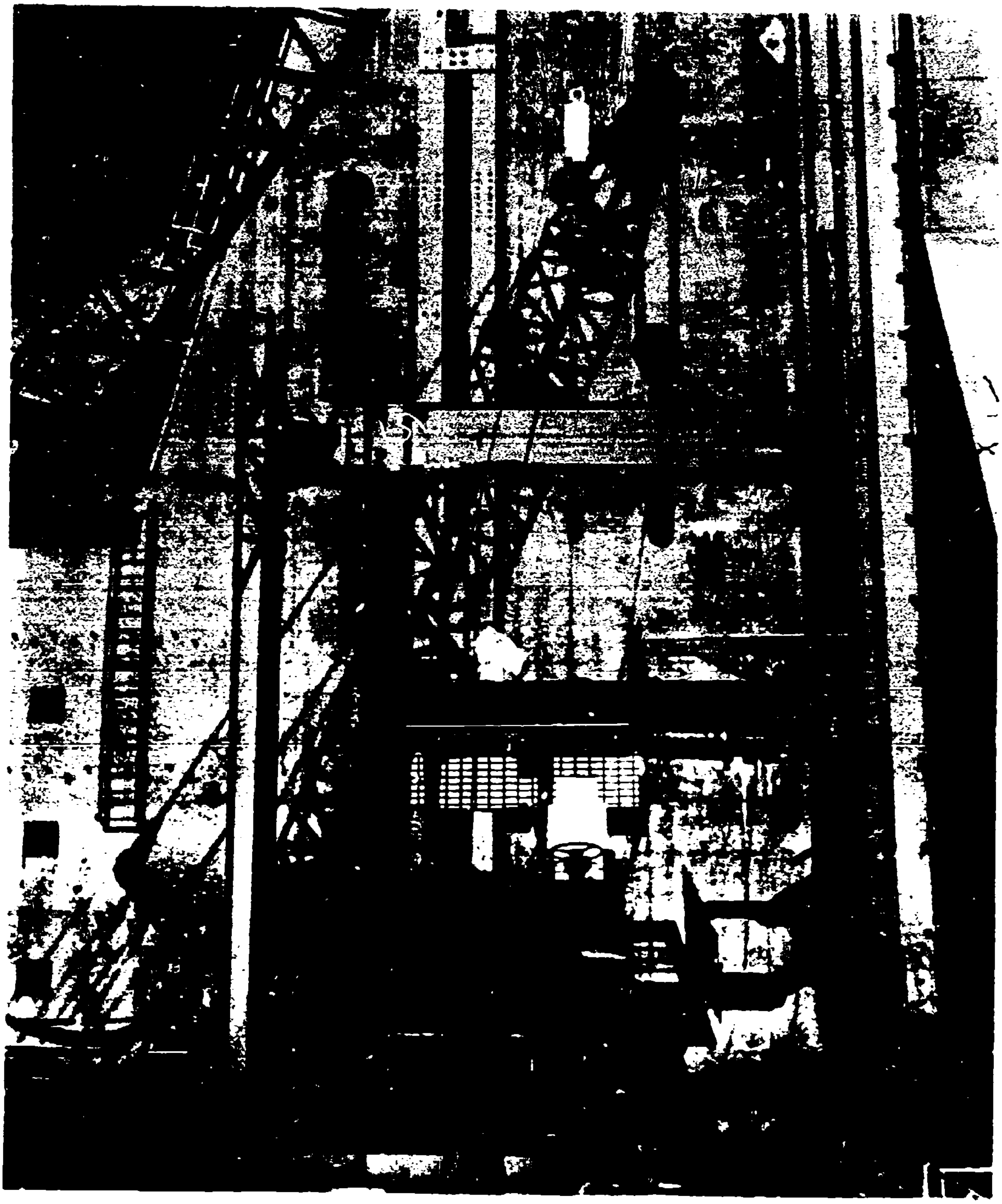


Figure 43 - Prototype Test Prior to FOPS Test

10327

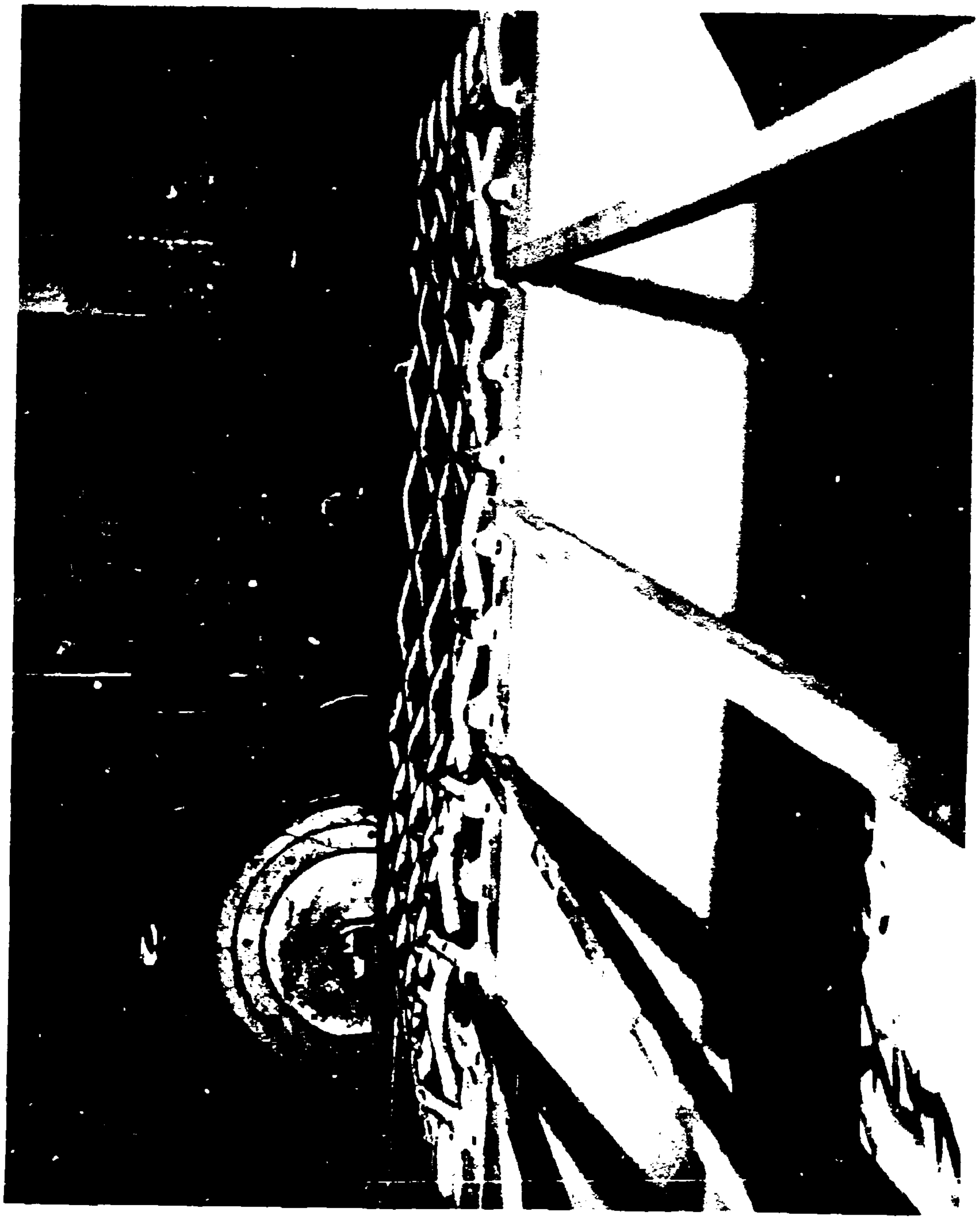


Figure 44 - Prototype Test - Protective Screen after FOPS test

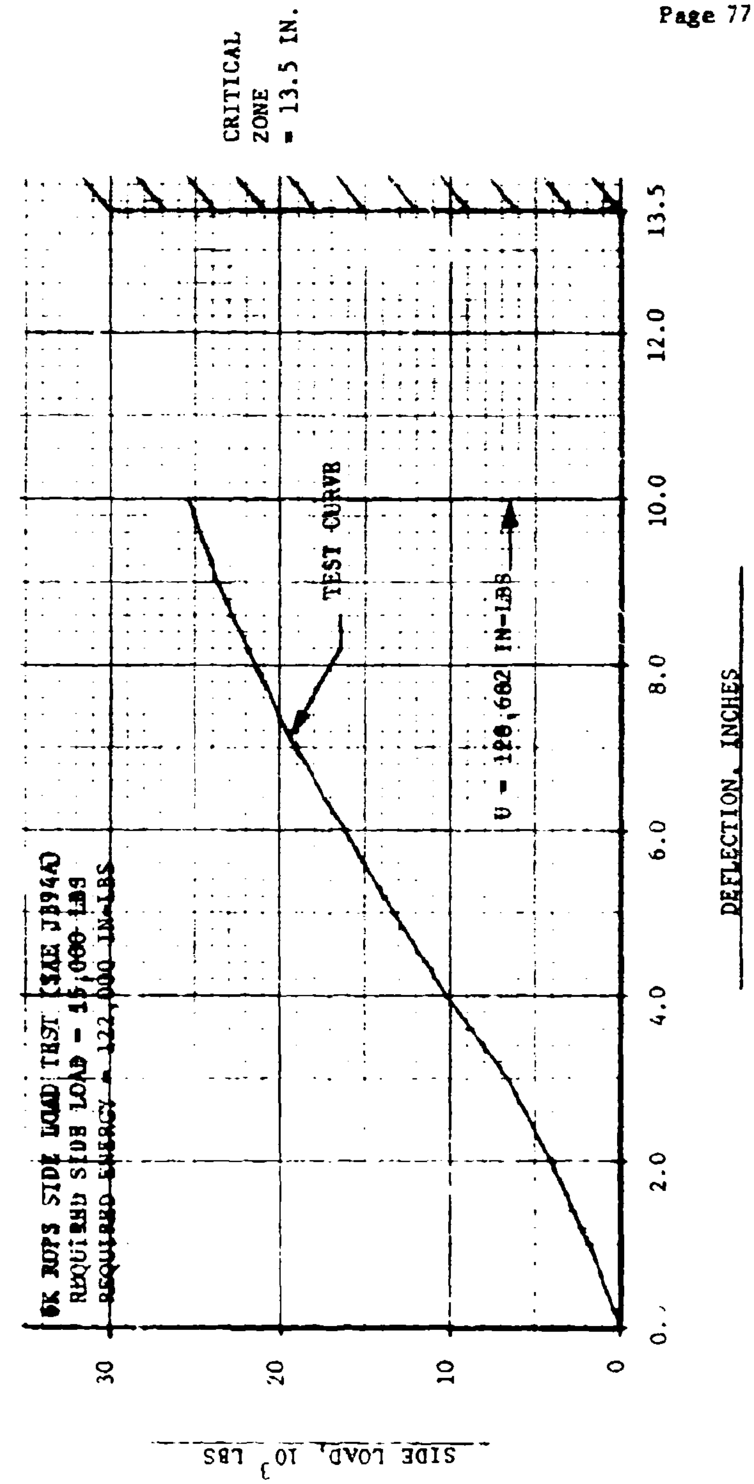


Figure 45 - Side Load Test Results

been noted in the development tests.

Careful consideration of the data indicated that the tolerances and design of the foot and socket had taken us out of the range of design characteristics of the development unit. Analysis of the previous design had varied the fixity of the lower end of the vertical legs in bending between pinned and fixed. Torsional rotation of the lower end was held to be negligible, an assumption in keeping with observed performance. In the prototype unit, however, the loosened tolerances and configuration of the foot and socket permitted enough torsional rotation to have an effect on deflection. Analytical considerations are presented in Appendix 6.7 where it is shown that with the inclusion of torsional rotation in the analysis, the deflection observed is predictable. It should also be noted that the torsional stiffness of the attach points contributed to the low initial stiffness observed during the Caterpillar 830MB and Clark 290M ROPS tests and is much more significant for 2 post designs than for 4 post. Figure 46 shows the vehicle at the maximum test load condition.

Review of strain data from the prototype test indicates higher strain than observed in the development test. Canopy gussets in the prototype test were in the material yield range as was one of the vertical tubes at its upper end whereas all points were within material yield stress in the development test. The level of strains reached are acceptable since maximum strain observed was only 2% of the minimum material capability and no excessive distortion was noted in the ROPS. The change in strain from the development test can be attributed to movement of the prototype foot in the socket which causes higher moments in the upper ends of the tube than in the development design and is discussed in greater detail in Section 5.2.2.3 and Appendix 6.7.

3. A vertical load of 23,500 lb, equal to the vehicle weight, was imposed at the geometric center of the ROPS roof as required by SAE Recommended Practice J394a. Vertical test loading results are shown in Figure 47 and Figure 48 shows the vehicle under maximum load. Adequacy for this loading condition is evident in both of these figures.

Upon completion of the certification test, some of the loading conditions were repeated with instrumentation located to obtain better definition of movement of the structure. These data are to assist in analysis of the deflection characteristics of the ROPS.

After the certification test, the prototype unit was completely disassembled from the vehicle and an overall visual inspection and dye penetrant inspection of all welds were performed. A slight crack was found in the weld between the vehicle frame and the bar which attaches the rear wheel structure to the frame. This area had been ground away to accommodate a dimensional discrepancy of the prototype ROPS attach structure. All other vehicle and ROPS areas were sound.

5.3 Field Rollover Test

5.3.1 Roll Analysis and Vehicle Preparation

The roll starting position used was chosen from five different potential

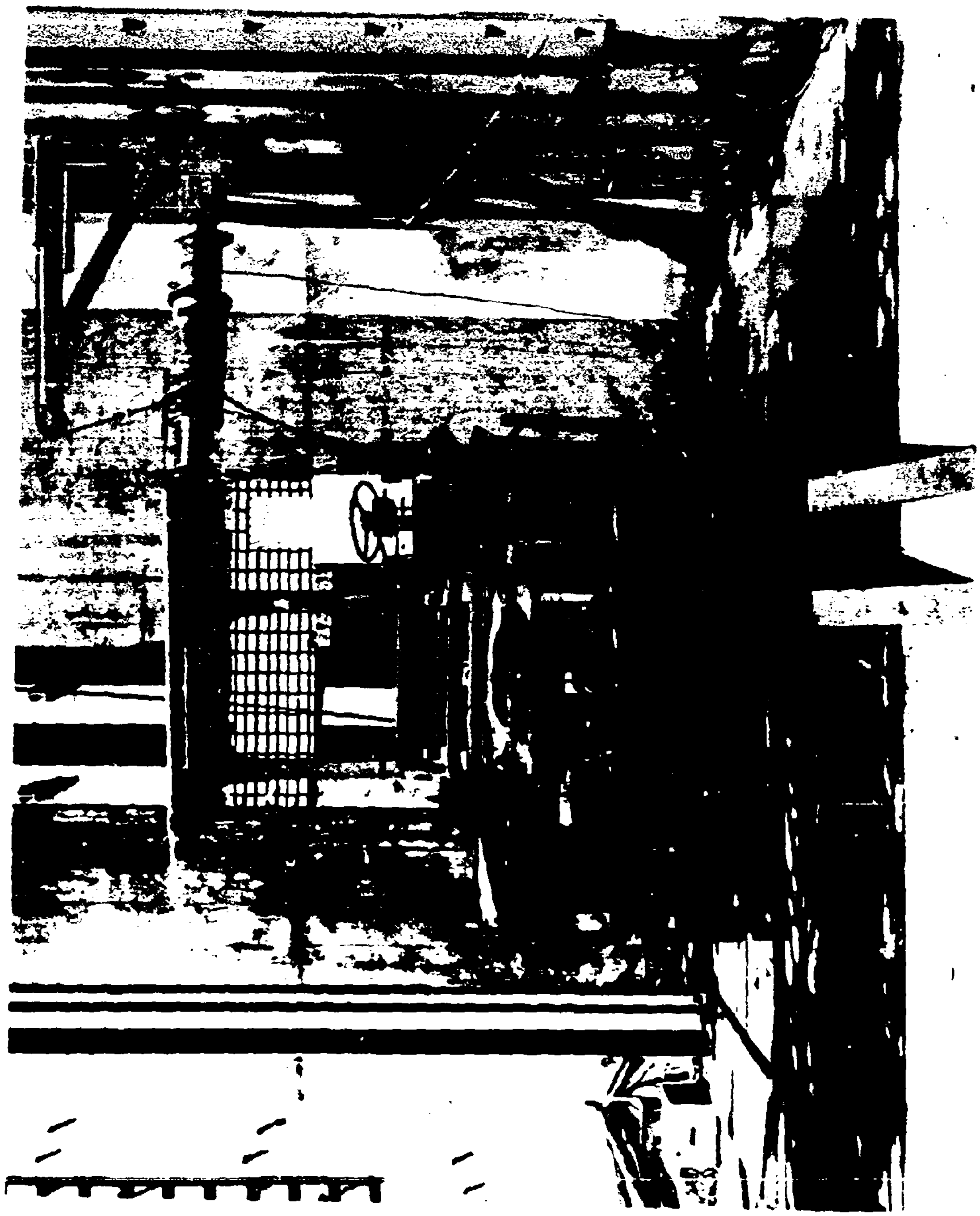


Figure 46 - Prototype Test - Maximum Side Load

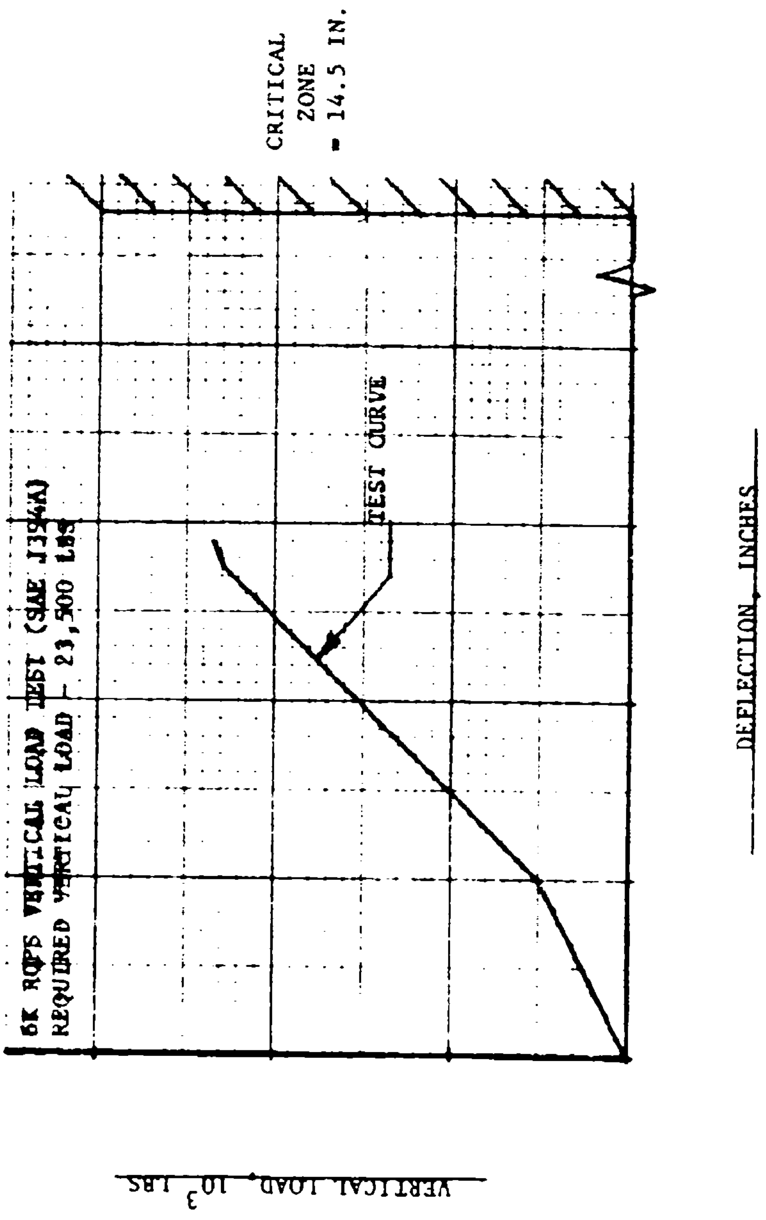


Figure 47 - Vertical Load Test Results

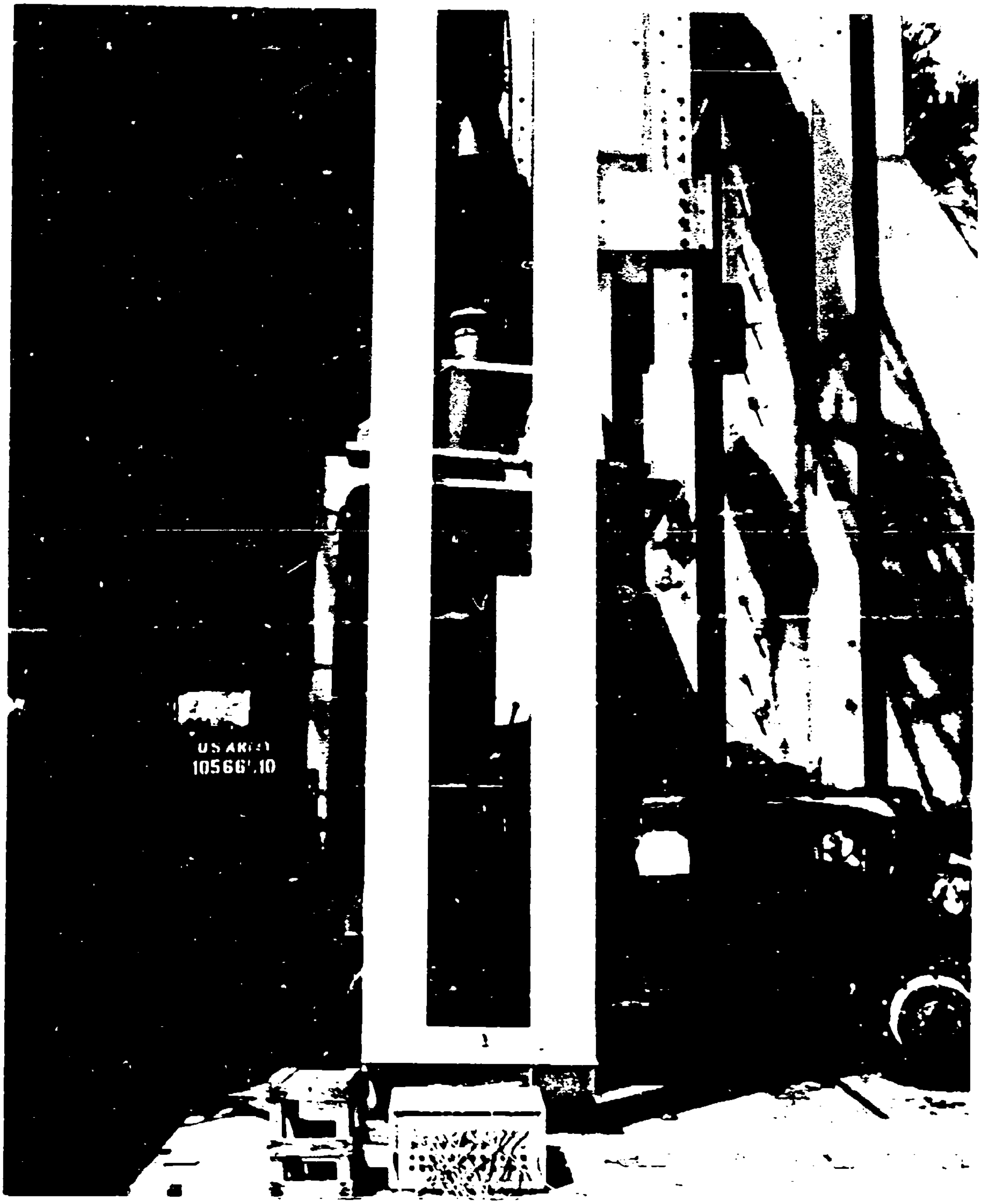


Figure 38 - Prototype Test Maximum Vertical Load

starting positions for producing the most realistic ROPS roll loads and for providing the greatest probability to induce a 360-degree roll. After the starting position was chosen, a dynamics analysis was performed to determine the required dropping height to complete the first roll. The analysis approach was to assume the energy developed from the initial drop plus roll had to be equal or greater than the energy required to raise the vehicle up and over the ROPS plus system energy losses. Since a roll experiences both side and vertical loads, system losses were assumed to be equal to the energy developed during the SAE side load test plus the SAE vertical load test. The analysis indicated the uphill wheel should be at least 16 inches vertically above the plane of the 32° hill with the vehicle tilted so the C.G. is approximately over the uphill wheels.

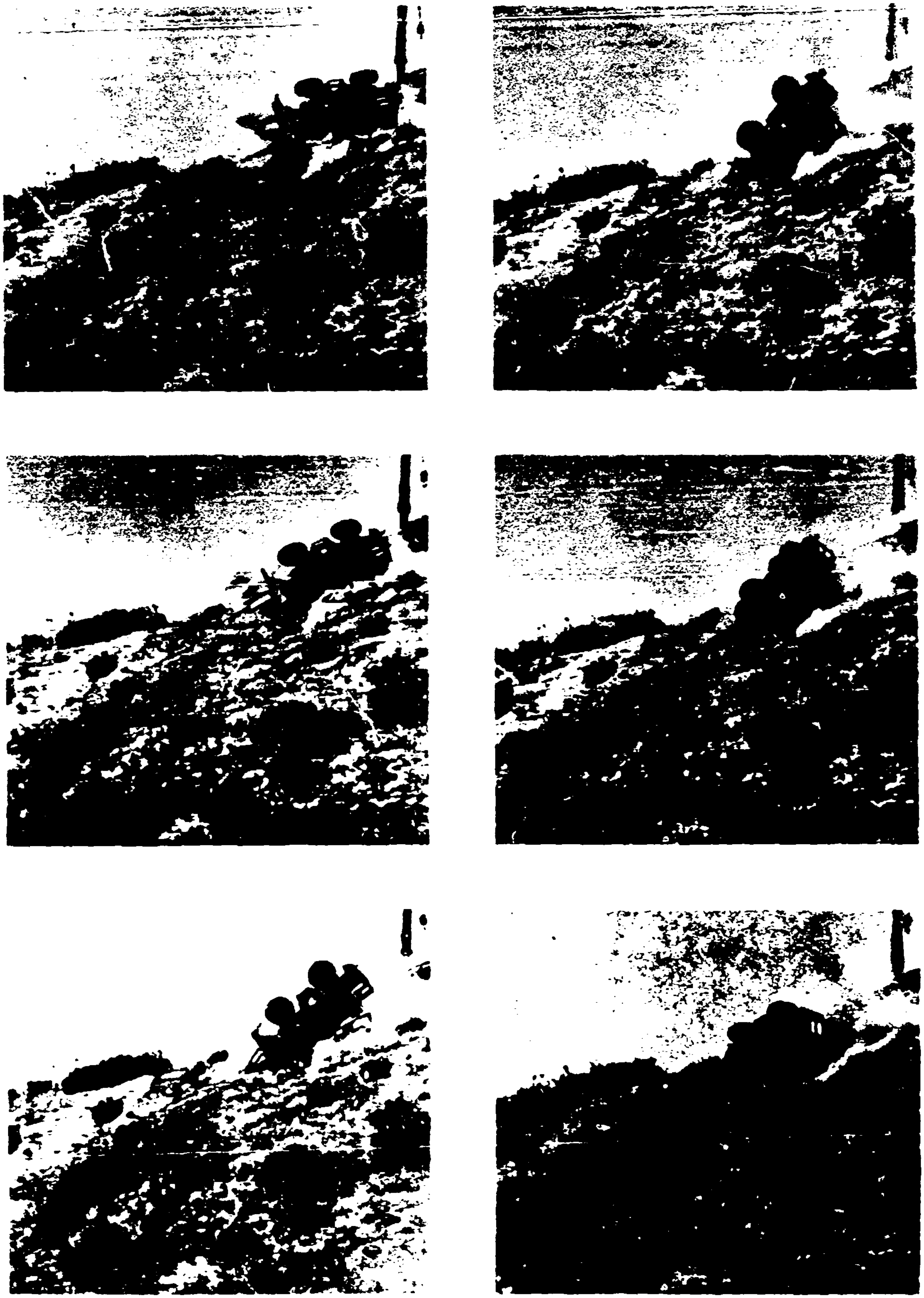
Before the roll test, a slight crack was found in a vehicle weld, as noted in Section 5.2.4.3. This weld was ground to remove all indications of the crack and rewelded to the original configuration. Since all of the vehicle and ROPS structure was sound, the decision was made to roll the ROPS and Type "F" vehicle from the certification test

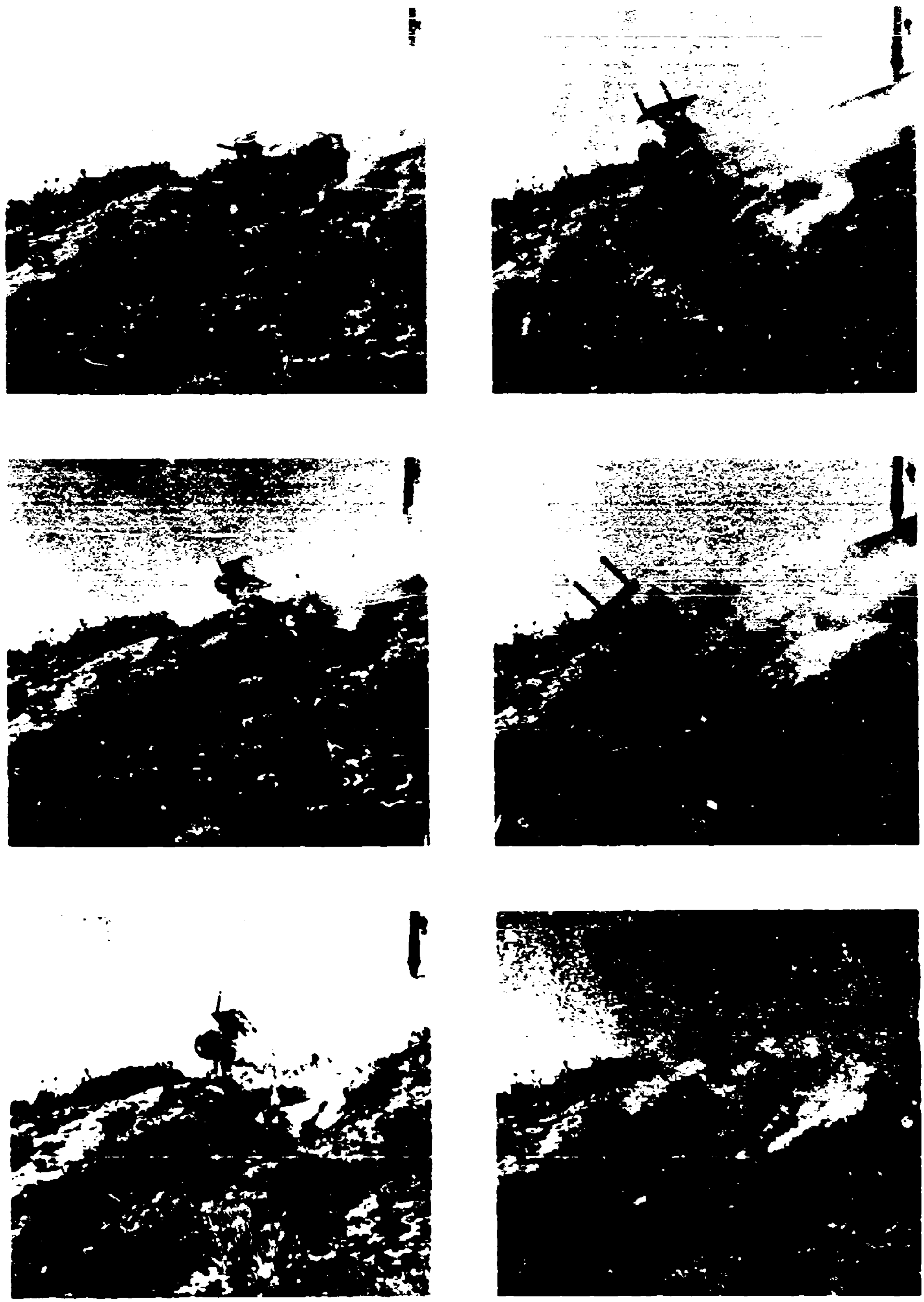
5.3.2 Roll Test

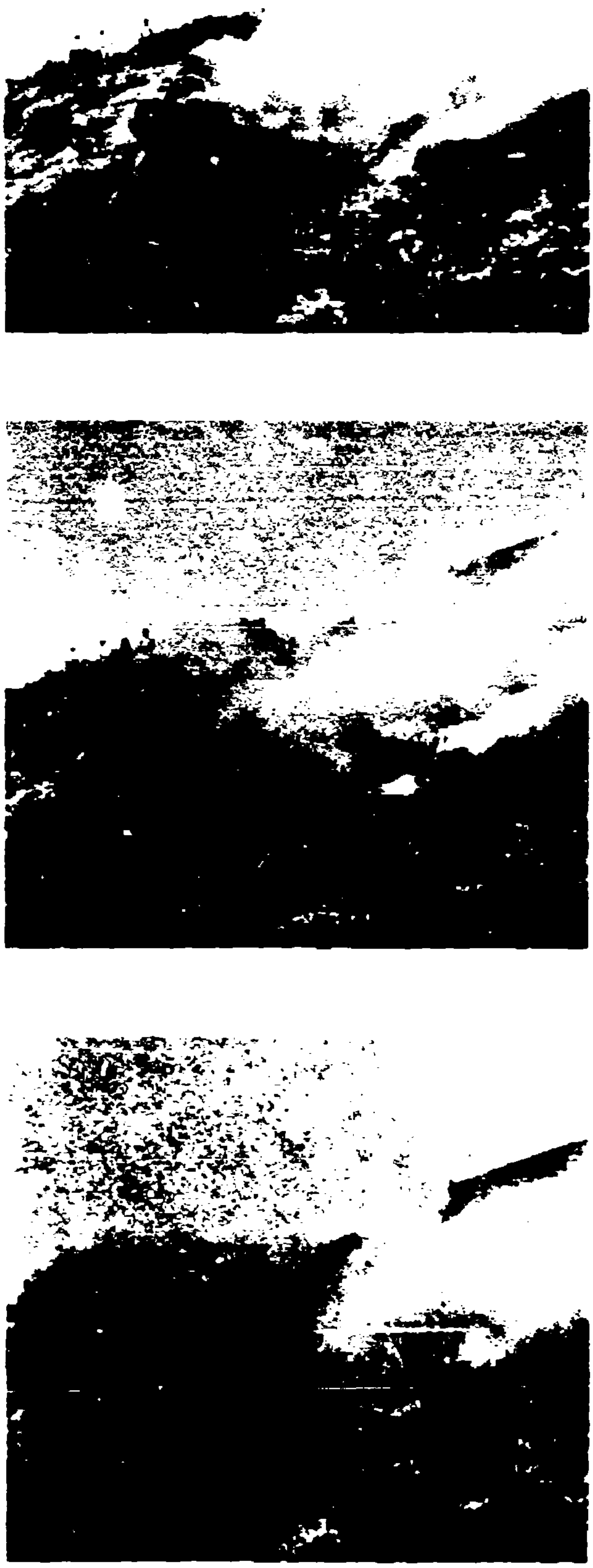
On October 11th, the roll-over test was conducted at the LPC Potrero facility. The vehicle was suspended over the test slope with its RH wheels on a platform. The cable holding the vehicle in this position was released and the left side of the forklift dropped onto the slope to start the roll. Figure 49 shows the roll sequence from still photos taken every 1/4 second. Deflection of the ROPS is evident in the 5th and 6th views from the combined side and vertical loading. The 7th and 8th views show that in the inverted position the load is imposed on the forward part of the ROPS. As the forklift goes from the 1/2 to 3/4 roll position, the aft end begins to go farther down hill than the forward end so that in the 11th view, an end-over-end roll starts which imposes forward and vertical loads on the ROPS. This roll continues until the vehicle is back on its wheels, just after the last picture in the sequence. Figure 50 shows the condition of the ROPS after this test. This same ROPS had been used in the prototype certification test and had some residual deformation, but most of the deformation seen in these figures came from the roll. Although there was more damage than in the certification static tests, the adequacy of the two-post design was substantiated by the severe conditions imposed on the ROPS in the roll test. The roll started by the left wheels dropping 110 inches before hitting the slope, which was inclined 32 degrees and was 100 ft long. The end-over-end roll was so severe that the shock of the last impact caused the counterweight to break loose. The structure holding the seat and operating controls was loosened and tilted over although it is possible that some of the bolts holding this structure may have been missing before the test.

5.4 ROPS Installation and Delivery

A ROPS system was installed on a type A Forklift to check out the installation instructions and to provide a system for performance testing at USAMERDC. The time required for the various operations was:







B

[illegible] Forklift Rollover Test

(Sheet [illegible])

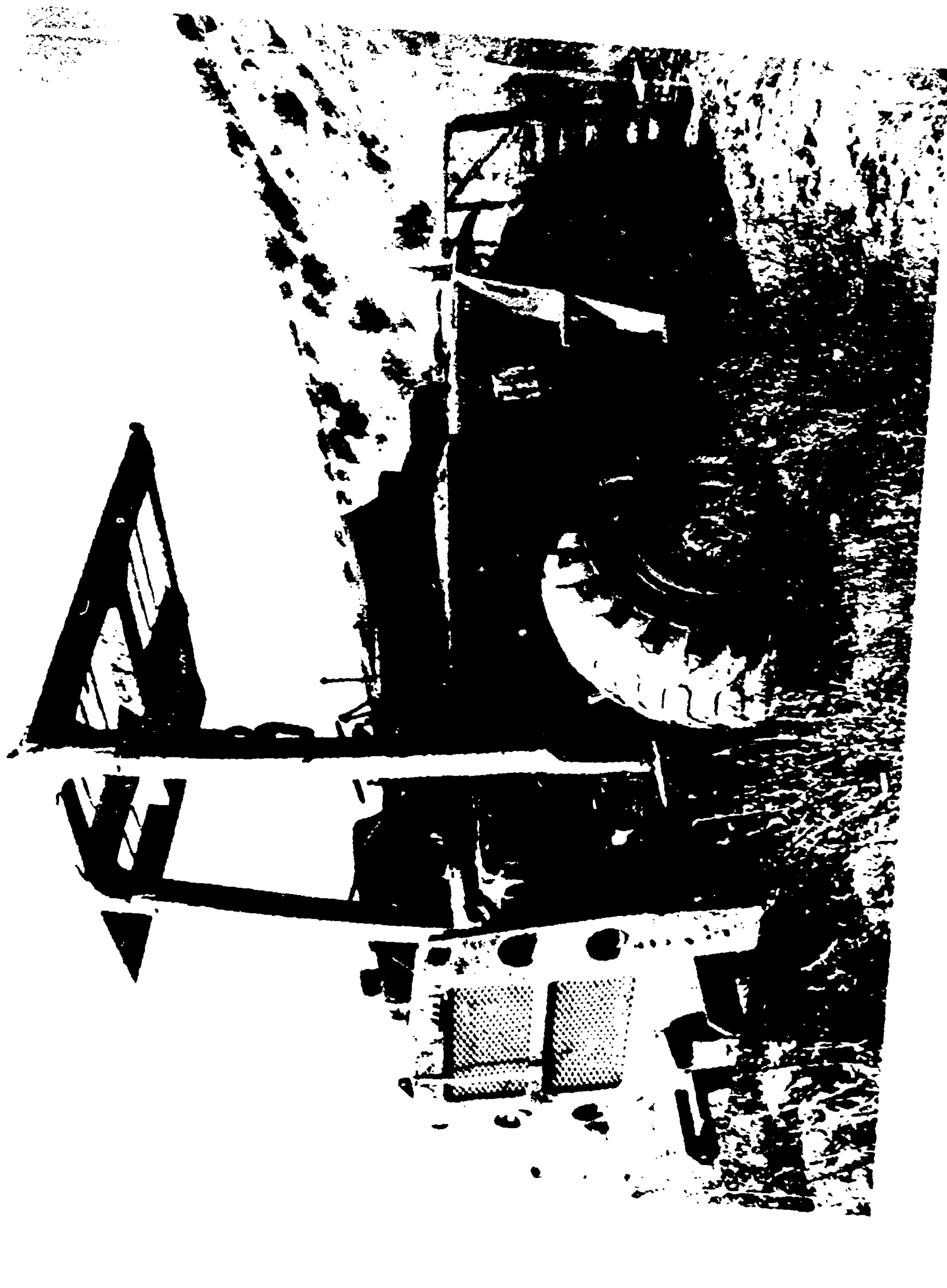


Figure 30 - 6K Forklift - Condition After Rollover Test

1.	Chassis preparation	10 manhours
2.	Installation of attachment structure (includes 8 hours welding)	24
3.	Installation of ROPS	3
4.	Re-installation of vehicle components	16
		53 manhours

Not included in this figure are approximately 12 man-hours required to rework metal parts such as the fenders. Since the method of rework was developed during the process of modifying these items, the time spent is not representative of that now required with the instructions available. Figure 51 shows the right rear portion of the vehicle with the tie down removed ready for fit-up of the attachment structure. Figure 52 shows the attachment structure being located for installation. Figure 53 show the ROPS installed and ready for use on the forklift. This unit was shipped by commercial truck to MERDC on October 30.

The complete installation instructions are included in Appendix 6.8.

The ROPS system to be used by USAMERDC personnel for early service experience in ROPS installation was shipped from Portland, Oregon on October 4th and delivered to Ft. Belvoir on October 24th.

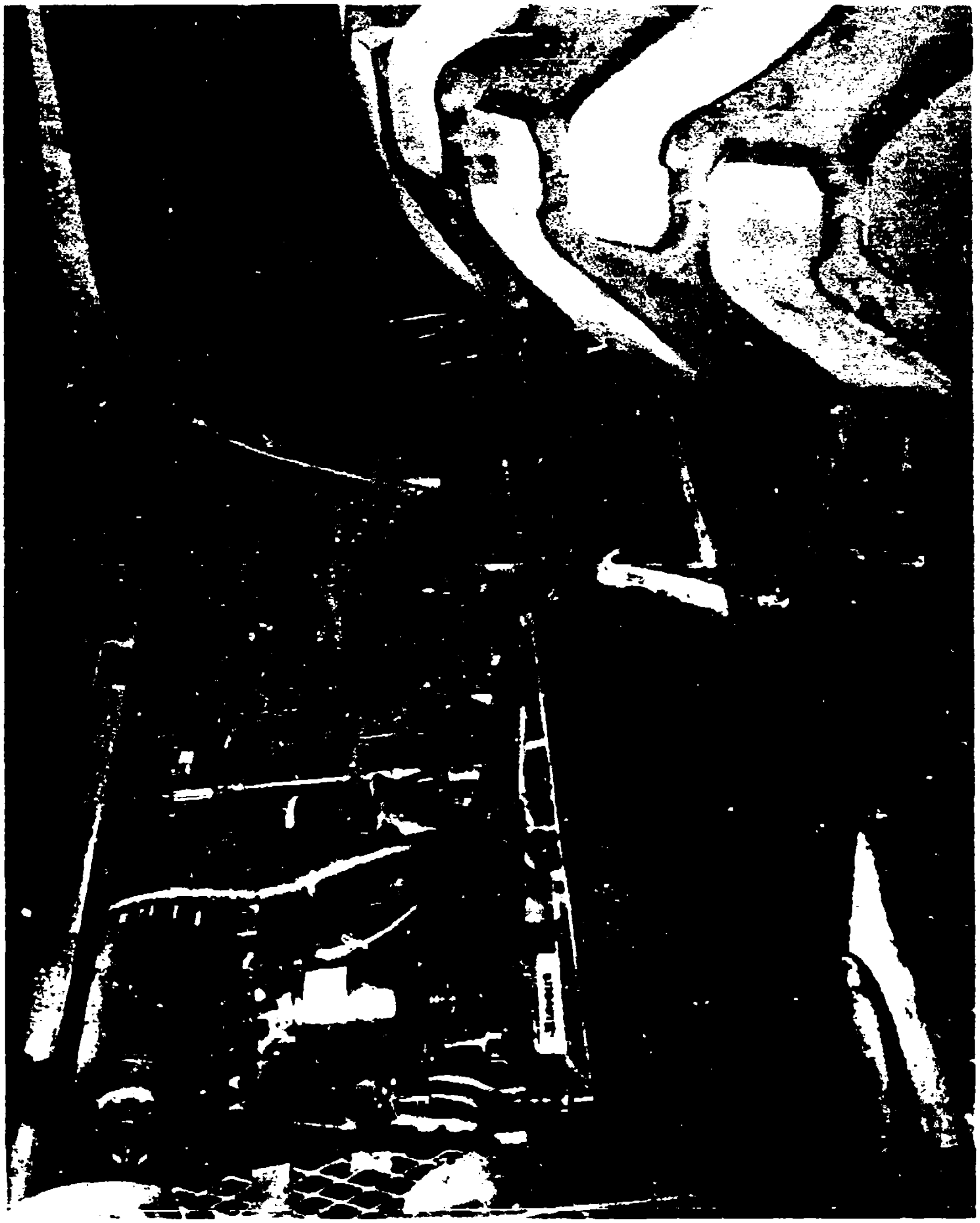


Figure 51 - 6K Forklift - Tiedown Removed in Preparation for ROPS Installation

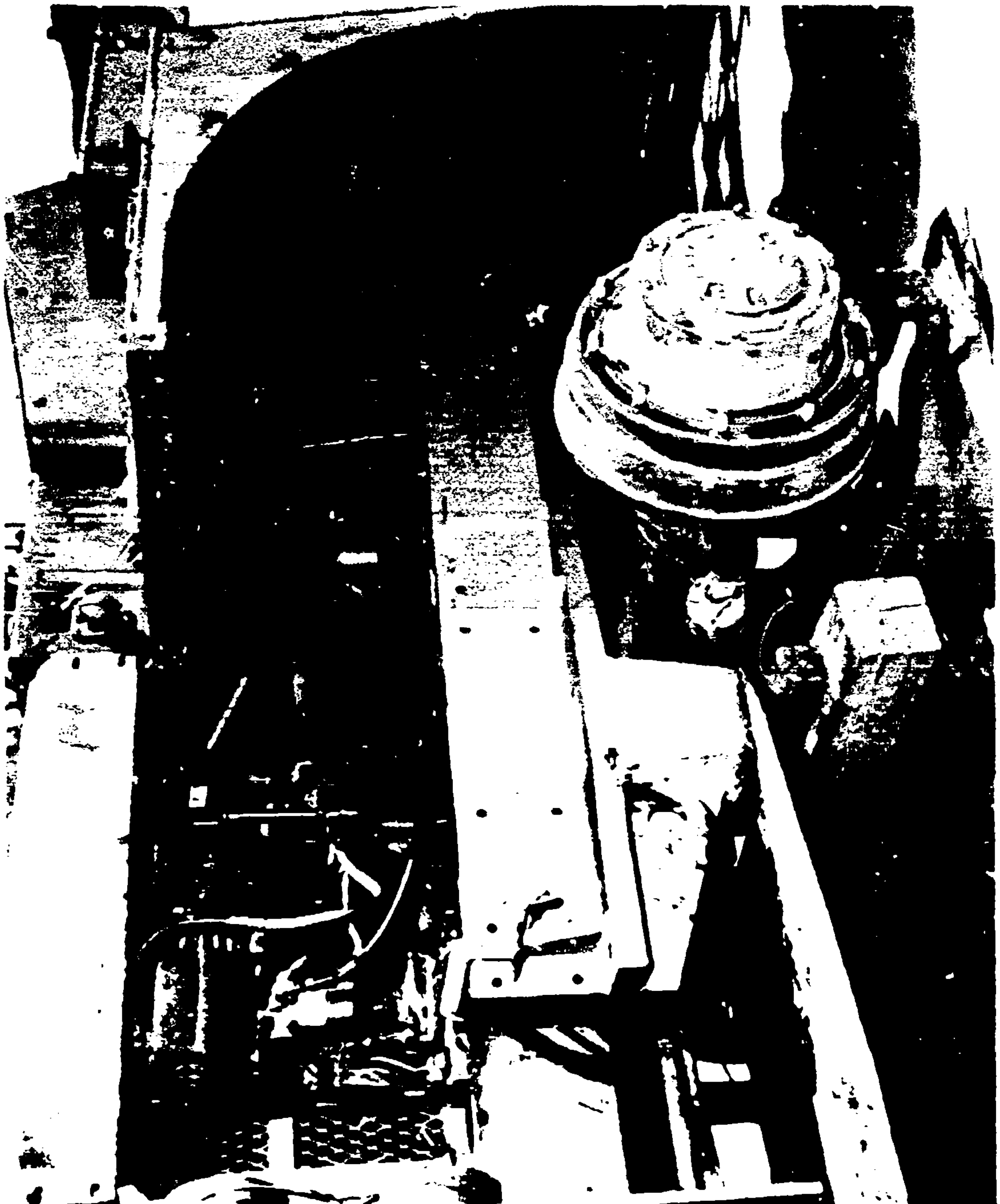


Figure 52 - 6K Forklift - Installation of Frame Reinforcement

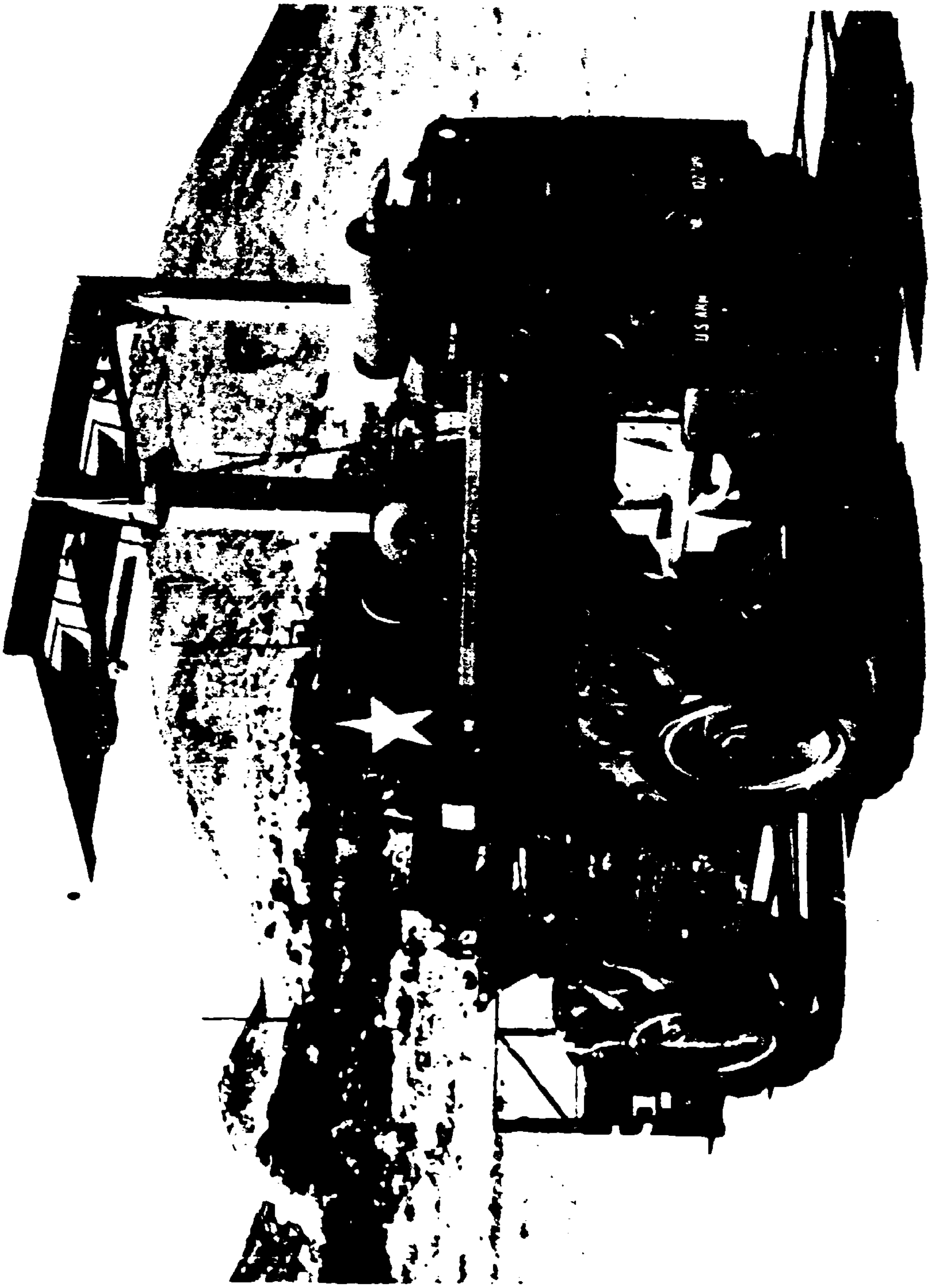


Figure 34 - 6K Forklift with ROPS

6.0 APPENDICES

APPENDIX 6.1

MATERIAL AND PROCESS SPECIFICATIONS

APPENDIX 6.1.1

MATERIAL SPECIFICATION EMSD103,

STEEL, CARBON, HIGH STRENGTH

Lockheed Propulsion Company
CODE IDENT. NO. 06481

EMSD103
30 October 1972

MATERIAL SPECIFICATION

STEEL, CARBON, HIGH STRENGTH

1. SCOPE

1.1 This specification covers the requirements for structural steel with low-temperature impact strength properties intended for use in roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

Specifications

ASTM A 6	General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use
ASTM A 20	General Requirements for Delivery of Steel Plates for Pressure Vessels
ASTM A 370	Mechanical Testing of Steel Products, Methods and Definitions for
ASTM A 516	Carbon Steel Plates for Pressure vessels for Moderate and Lower Temperature Service
ASTM A 593	Charpy V-Notch Testing Requirements for Steel Plates for Pressure vessels

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

ENGINEERING STANDARDS	TECHNICAL SPECIALIST:	ENGRG. SPEC COMMITTEE
3/26/73	3-22-73	3/26/73
	PROJECT 3/26/73	

FORM NO. LPC 1423-A

3. REQUIREMENTS

3.1 Material. Steel furnished under this specification shall meet the requirements specified herein and ASTM A 516, Grade 65, or Grade 70. In the event of a conflict, the requirements herein apply.

3.2 Chemical composition. The composition shall comply with the following:

Carbon, percent	0.26 maximum
Manganese, percent	0.85 to 1.20
Silicon	*
Sulfur	0.04 maximum
Phosphorus	0.05 maximum

* Silicon killed fine grain practice for improved notch toughness.

3.3 Mechanical properties. The mechanical properties shall be as follows:

Tensile

Tensile strength, psi	70,000 to 90,000
Yield point, psi	38,000 minimum
Elongation in 2 inches, percent	20 minimum

Impact (Tested by the Charpy V-notch method in accordance with ASTM A 593.)

Specimen Size	Test temperature	Impact value, Minimum
10 mm x 10 mm	-20°F (-30°C)	8 ft. lb. (10.8J)
10 mm x 5 mm	-50°F (-45°C)	5 ft. lb 6.8J)
10 mm x 2.5 mm	-70°F (-57°C)	2 ft. lb. (2.7J)

3.4 Manufacturing tolerances, surface condition, and workmanship shall be in accordance with either ASTM A 6 or ASTM A 20.

4. QUALITY VERIFICATION

4.1 Certifications. Compliance with the specified requirements shall be verified for each heat or heat lot by certified test results from the supplier.

APPENDIX 6.1.2

MATERIAL SPECIFICATION EMSD104,

STEEL TUBING, CARBON

Lockheed
Propulsion
Company
CODE IDENT. NO. 06401

LOCKHEED

EMSD104
30 October 1972

MATERIAL SPECIFICATION

STEEL TUBING, CARBON

1. SCOPE

1.1 This specification covers the requirements for square, rectangular, and round structural steel tubing with low-temperature impact strength properties intended for use in roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

Specifications

ASTM A 370	Mechanical Testing of Steel Products, Methods and Definitions for
ASTM A 500	Cold-formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
ASTM A 501	Hot-formed Welded and Seamless Carbon Steel Structural Tubing

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

ENGINEERING STANDARDS	TECHNICAL SPECIALIST:	ENGRG SPEC COMMITTEE
3/26/73	3-21-73	3/26/73
	PROJECT 3/26/73	

FORM NO LPC 1423-A

3. REQUIREMENTS

3.1 Material. Steel furnished under this specification shall meet the requirements specified herein and either ASTM A 500 or ASTM A 501. In the event of a conflict, the requirements herein apply.

3.2 Chemical composition. The composition shall be in accordance with ASTM A 500 or ASTM A 501.

3.3 Mechanical properties. The mechanical properties shall be as follows:

Tensile

Tensile strength, psi	60,000 to 80,000
Yield point, psi	50,000 minimun
Elongation in 2 inches, percent	20 minimum

Impact (Tested by the Charpy V-notch method in accordance with ASTM A 370.)

Specimen size	Test temperature	Impact value, Minimum
10 mm x 10 mm	-20°F (-30°C)	8 ft. lb. (10.8J)
10 mm x 5 mm	-50°F (-45°C)	5 ft. lb. (6.8J)
10 mm x 2.5 mm	-70°F (-57°C)	2 ft. lb. (2.7J)

3.4 Manufacturing tolerances, surface condition, and workmanship shall be in accordance with either ASTM A 500 or ASTM A 501.

4. QUALITY VERIFICATION

4.1 Certifications. Compliance with the specified requirements shall be verified for each heat or heat lot by certified test results from the supplier.

APPENDIX 6.1.3

PROCESS SPECIFICATION DPSF100, WELDING REQUIREMENTS FOR ROLLOVER PROTECTIVE STRUCTURES

Lockheed Propulsion Company
CODE IDENT. NO. 06401

LOCKHEED

DPSF100
6 November 1972

PROCESS SPECIFICATION

WELDING REQUIREMENTS FOR ROLL OVER PROTECTIVE STRUCTURES

1. SCOPE

1.1 This specification covers the requirements for weld fabrication of roll over protective structures.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest revision shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

<u>Specifications</u>

ASTM A 233	Mild Steel Arc-Welding Electrodes, Specification for
ASTM A 559	Mild Steel Electrodes for Gas Metal-arc Welding, Specification for

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

ENGINEERING STANDARDS	TECHNICAL SPECIALIST:	ENGRG. SPEC COMMITTEE
3/16/73	2-19-73	3/16/73
	PROJECT 3/16/73	

FORM NO. LPC 1423-A

AMERICAN WELDING SOCIETY (AWS)

Specifications

AWS A5.1	Specifications for Mild Steel Covered Arc Welding Electrodes
AWS A5.18	Specification for Mild Steel Electrodes for Gas Metal-arc Welding

(Application for copies should be addressed to the American Welding Society, Inc., 345 East 47th Street, New York, New York 10017.)

3. REQUIREMENTS

3.1 Qualification of welders. Before assigning any welder to manual welding work the supplier shall furnish to the procuring activity certification that the welder has passed qualification testing as prescribed by any of the following listed codes for the type of welding operation to be performed. Such qualification shall have current effectivity as defined by the particular code.

(a) Standard Qualification Procedure of the American Welding Society

(b) Welding Qualification of the ASME Boiler and Pressure Vessel Code

3.2 Materials.

3.2.1 Base metals. The base metals to be welded in accordance with this specification are structural steel and castings as specified on the applicable drawing.

3.2.2 Filler metals. Filler metals shall be as follows:

(a) Shielded Metal-arc Welding -- Use ASTM A 233, Class E7018 or AWS A5.1, Class E7018.

(b) Gas Metal-arc Welding -- Use ASTM A 559 Class E70S-6 or E70T-5; or AWS A5.18-69, Class E70S-6 or E70T-5.

3.3 Equipment.

3.3.1 Arc welding machines. Arc welding machines shall be demonstrated to show ability to consistently reproduce machine setting variables within their usable range. Machines shall be provided with suitable means of controlling output variables.

3.3.2 Gas welding equipment. Gas welding equipment, such as torches and regulators, shall be of a standard type which have demonstrated ability to perform the functions intended and shall be capable of maintaining a uniform flame.

3.3.3 Calibration of equipment. Sufficient calibration of machine setting variables shall be maintained on all welding equipment so as to assure the reproducibility and the operational consistency of established production weld settings.

3.3.4 Supporting equipment. Jigs, clamping devices, and tack welding shall be used whenever necessary to prevent warping and ensure proper alignment of parts.

3.4 Welding method. Welding shall be performed by either the shielded metal-arc or gas metal-arc process. Welding shall be performed in any position necessary to achieve a satisfactory weldment.

3.4.1 Cleaning. All weld zone areas of parts shall be free from rust, scale, paint, grease, and other foreign matter. All slag and spatter shall be completely removed from each weld bead before depositing the next successive bead. When a through-weld is to be obtained by welding both sides of a joint, the root of the first weld shall be chipped or ground to sound metal before welding the second side.

3.4.2 Weld joint fit-up. Weld joint fit-up shall be such that the configuration requirements of the applicable drawing are met.

3.5 Weld quality.

3.5.1 Workmanship. Finished welds shall be smooth and free of undercutting. All undercutting shall be removed or faired in by grinding. Weld beads shall be uniform in width and shall be smooth and spatter free.

3.5.2 Surface defects. Any cracks or porosity on the surface of a weld bead shall be removed by grinding before depositing the next successive bead.

4. QUALITY VERIFICATION

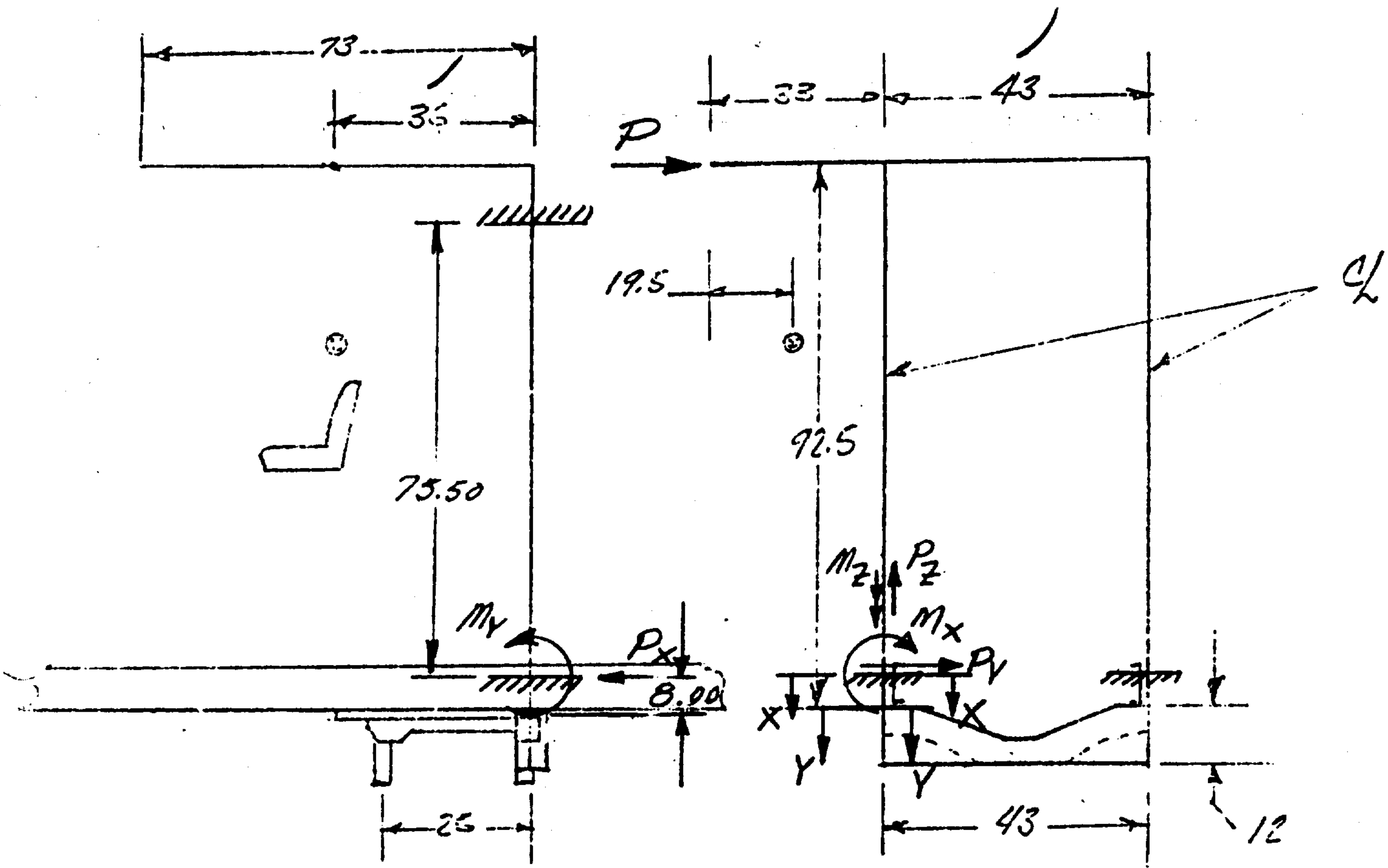
4.1 Inspection. All welds shall be visually inspected to verify compliance with this specification.

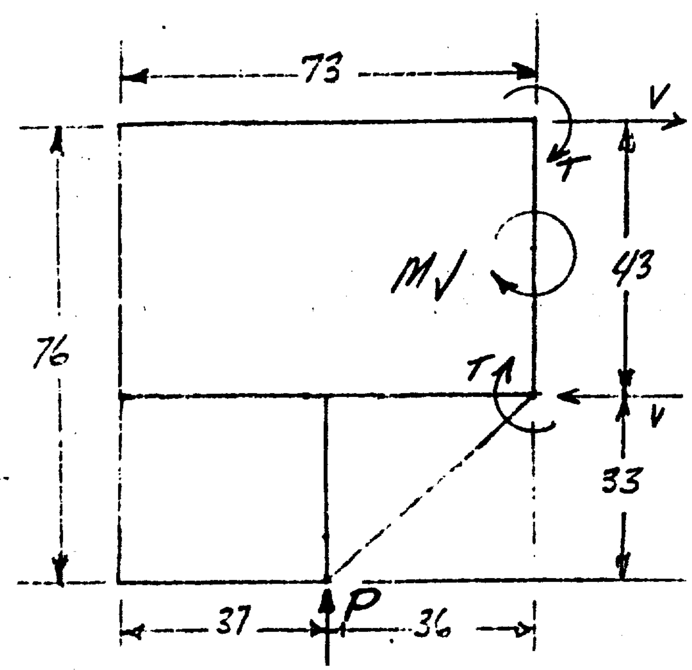
APPENDIX 6.2

STRUCTURAL ANALYSIS OF DEVELOPMENT UNIT

Ca K - Rods

IV. GEOMETRY



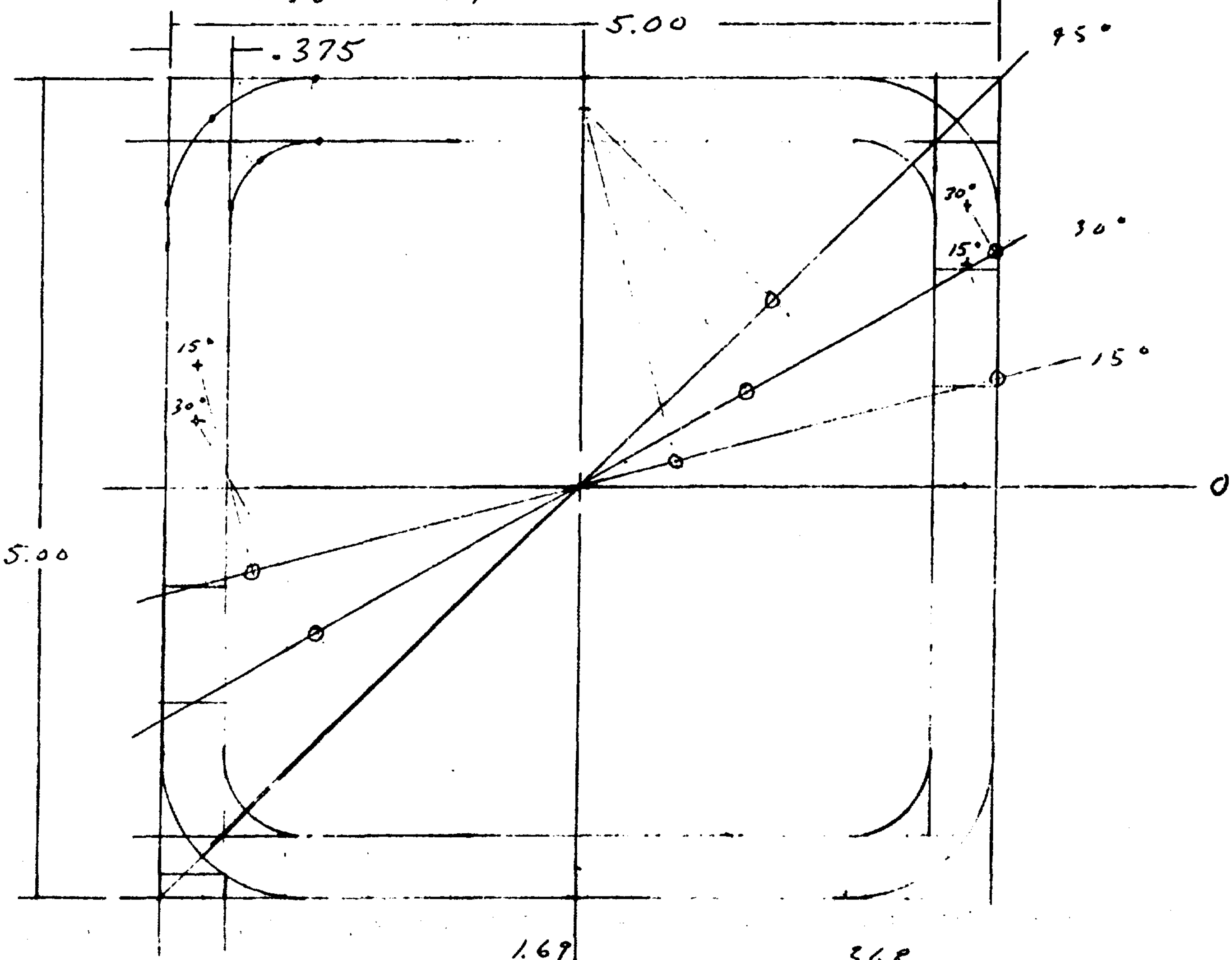


ZAHAREE
2/22/73

6K FORKLIFT ROPS

BENDING MOMENT CAPABILITY

FOR $F_{TU} = 64,000$ PSI :



$$\overset{1.69}{} \qquad \overset{3.68}{}$$

$$B.M.(0°) = 64{,}000 \times 2\left[2.125^2 \times .375 \times \left(\tfrac{2}{3}\right) + 4.25 \times .375 \times 2.31\right] = 687{,}000 \text{ IN\#}$$

$\times 1.185 = 814$

$$\overset{1.088}{} \qquad \overset{3.600}{} \qquad \overset{9.48}{}$$

$$B.M(15°) = 64{,}000 \times 2 \times .375\left[1.51 \times .72 + 2.73 \times 1.32 + 4.25 \times 2.23\right] = 683{,}000 \text{ IN\#}$$

$\times 1.185 = 806$

$$\overset{.265}{} \qquad \overset{5.07}{} \qquad \overset{8.45}{}$$

$$B.M.(30°) = 64{,}000 \times 2 \times .375\left[.78 \times .34 + 3.43 \times 1.48 + 4.25 \times 1.99\right] = 672{,}000 \text{ IN\#}$$

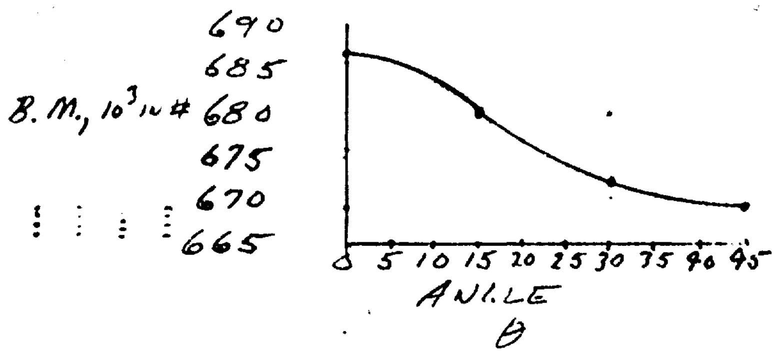
$\times 1.185 = 795$

$$B.M(45°) = 64{,}000 \times 4 \times .375\left[4.25 \times 1.64\right] = 669{,}000 \text{ IN\#}$$

$\times 1.185 = 793$

6K FORKLIFT ROPS BENDING MOMENT CAPABILITY

BENDING MOMENT VS. ANGLE



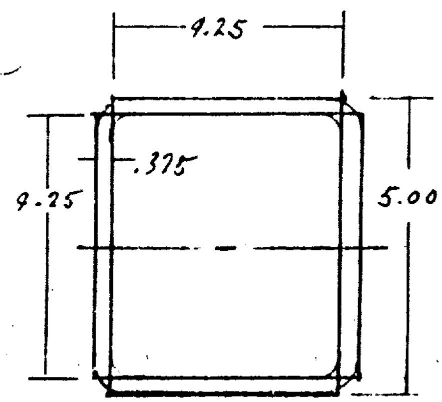
$\times \frac{77.4}{64} \times .97$

ROPS STANDARD MOMENT VS TORSION STIFFNESS CALC.

PLASTIC

MOMENT: FOR $M_V = 100{,}000$ IN#, $V = \frac{100{,}000}{43} = 2325\#$

$L_{EFF} = 75.50/2 = 37.75$ IN



$$\delta = \frac{PL^3}{3EI}(2) = \frac{2325 \times \overline{37.75}^3 \times 2}{3 \times 29 \times 10^6 \times 21.95} = .131 \text{ IN}$$

(2) FACTOR FOR TWO BEAMS; TOP & BOTTOM HALVES.

TORSION: FOR $M_V = 100{,}000$ IN#,
$T = 50{,}000$ IN#

$$I = \frac{.75 \times \overline{4.25}^3}{12} + \frac{4.25(\overline{5.00}^3 - \overline{4.25}^3)}{12}$$

$= 21.95 \text{ IN}^4$

$$\theta = \frac{TL}{KG} = \frac{50{,}000 \times 92.5}{40.2 \times 11 \times 10^6} = .0105$$

$$\delta = R\theta = \frac{43}{2} \times .0105 = .225 \text{ IN}$$

$$K_T = \frac{4A^2t}{L} = \frac{4 \times \overset{457}{4.625^4} \times .375}{4 \times 4.25}$$

$= 40.2$

% M_V REACTED BY MOMENT $= \frac{.225}{.225 + .131} \times 100 = 60\%$

% M_V REACTED BY TORSION $= \frac{.131}{.225 + .131} \times 100 = 40\%$

ZAHAREE
2/23/73

6K FORKLIFT ROPS + SIZING

DUE TO 'P' APPLIED 36 IN FROM VERTICAL LEGS: (PG. 1)

$$P_Z = \frac{92.5}{43 \times 2} P = 1.075\ P$$

$$P_X = 60\% \left(\frac{36}{43} P \right) = .502\ P \qquad (PG.3)$$

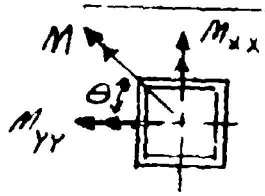
$$P_Y = .500\ P$$

$$M_X = \frac{P}{2} \times \frac{L_{EFF}}{2} = \frac{P}{2} \times \frac{75.50}{2} = 18.90\ P$$

$$M_Y = P_X \times \frac{L_{EFF}}{2} = .502\ P \times \frac{75.50}{2} = 19.0\ P$$

$$M_Z = 40\% \left(\frac{36\ P}{2} \right) = 7.2\ P$$

SECTION XX



$M = 18.90\ P \leftrightarrow 19.00\ P = 26.9\ P$ AT $\theta = 45°$

FROM PGS 2, 3 ALLOW B.M. AT 45°
= 669,000 IN#

$26.9\ P = 669,000$ IN#

$$P = \frac{669000}{26.9} = 24,900\ \#$$

1185

$$\frac{K_{ACT}}{K} = \frac{1.47}{1.50} = .98$$

$$MAT'L\ CORR = \frac{77.4}{64.0} = 1.21$$

$$P_{CORR} = .98 \times 1.21 \times 24,900 = 29,500\ \#$$

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6K FORKLIFT ROPS

BASE STRUCTURE CHECK - SECTION Y-Y PGS 1, 7A

(IN MOUNTING SOCKET): $P = 29{,}500\#$ (PG. 4)

$$P_X = .5P = 14{,}750\#$$

$$P_Y = .5P = 14{,}750\#$$

$$P_Z = 1.075P = 1.075 \times 29{,}500 = 31{,}700\#$$

$$M_X = 18.90P + 8.00P_Y$$

$$= \underbrace{18.90(29{,}500)}_{557{,}000} + \underbrace{8.00(14{,}750)}_{118{,}000} = 675{,}000\ IN\#$$

$$M_Y \approx M_X = 675{,}000\ IN\#$$

$$M_Z = 7.2P = 7.2(29{,}500) = 212{,}000\ in\#$$

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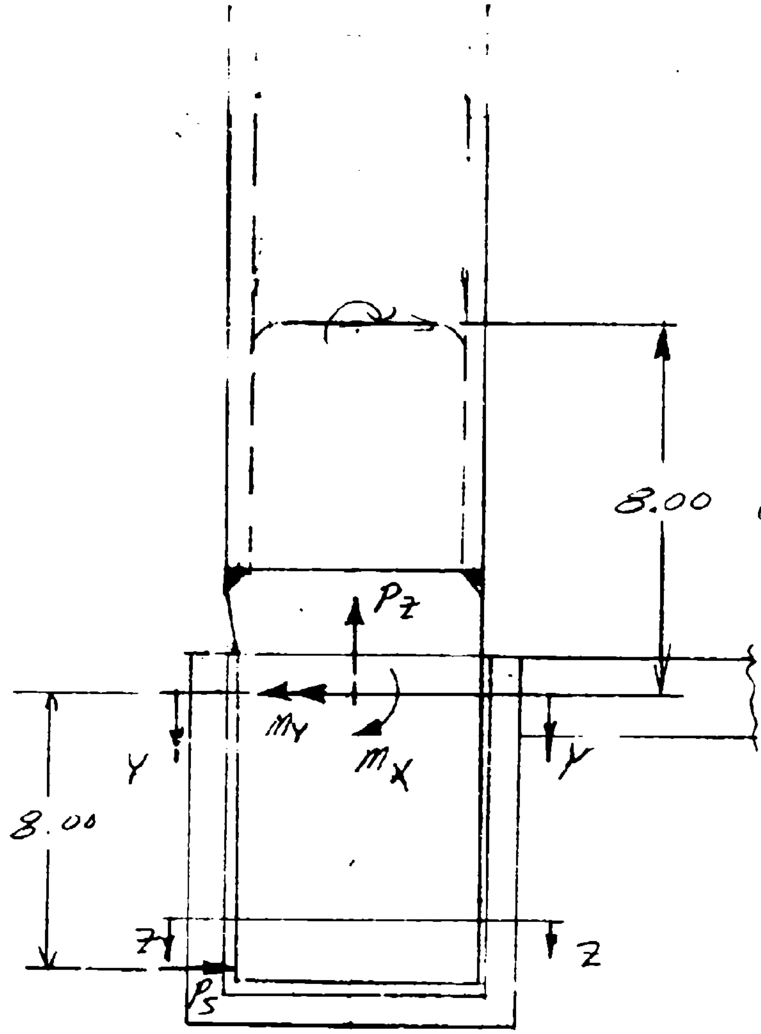
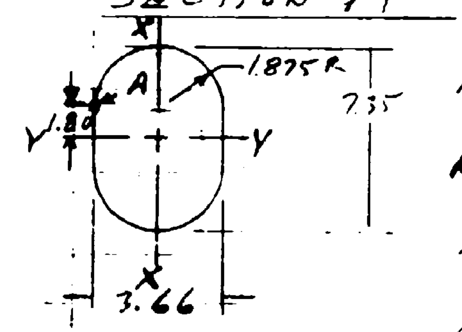
2/28/73
6K FORKLIFT ROPS



SECTION YY



$P_Z = 31{,}700$ # $P_X = P_Y = 14{,}750$ #

$M_X = 675{,}000$ in #

$M_Y = M_X = 675{,}000$ in #

$M_Z = 212{,}000$ in #

$A = 24$ in^2
I_{XX} 23.5 in^4
$I_{YY} = 91.5$ in^4

A — PT. A ;

$f_T = 31{,}700/24 = 1300$ PSI

$f_{bX} = 675{,}000 \times 1.83/23.5 = 52{,}500$ PSI

$f_{bY} = 675{,}000 \times \boxed{1.80}/91.5 = 13{,}300$ PSI

$S.F._{YIELD} = \dfrac{1.28 \times 38{,}000}{52{,}500 + 13{,}300} = \underline{0.74}$ $S.F._{ULT} = \dfrac{1.5 \times 70000}{52{,}500 + 13{,}300} = \underline{1.60}$

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2/28/73
SECTION X-X

S.F. ULT = 1.60 IS INACCURATE. COMPARE CAPABILITY OF SECTION Y-Y TO ROPS TUBE.

$$CAPABILITY = 100\% \times \frac{F_{TU_{XX}}}{F_{TU_{ROPS}}} \times \frac{Z_{XX}}{Z_{ROPS}} \times \frac{M_{ROPS}}{M_{XX}}$$

$$\frac{F_{TU_{XX}}}{F_{TU_{ROPS}}} = \frac{70}{70} = 1.00$$

$$\frac{Z_{XX}}{Z_{ROPS}} = \frac{\frac{23.5}{1.83}}{\frac{21.9}{2.50}} = \frac{12.80}{8.77} = 1.46$$

12.8

8.77

$$\frac{M_{ROPS}}{M_{XX}} = \frac{18.90(29500)}{675,000} = .825$$

557000

$$CAPABILITY = 100 \times 1.00 \times 1.46 \times .825 = 121.0\ \%$$

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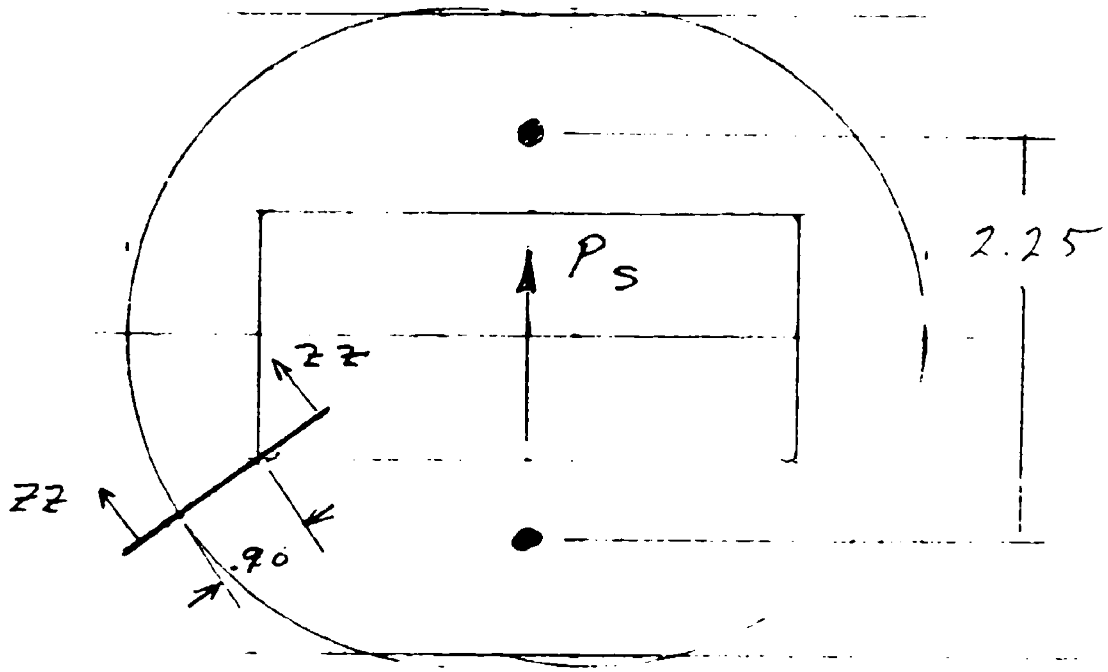
5K FORKLIFT ROPS

SECTION Z - Z (PG. 7A)

$M_x = 675{,}000$ IN # (PG. 7)

$P_S = M_x / 8.00 = 675{,}000 / 8.00 = 84{,}000$ #



$q = 84{,}000 / 2.25 = 37{,}400$ PSI

SECTION ZZ - ZZ

$t = .53$ IN

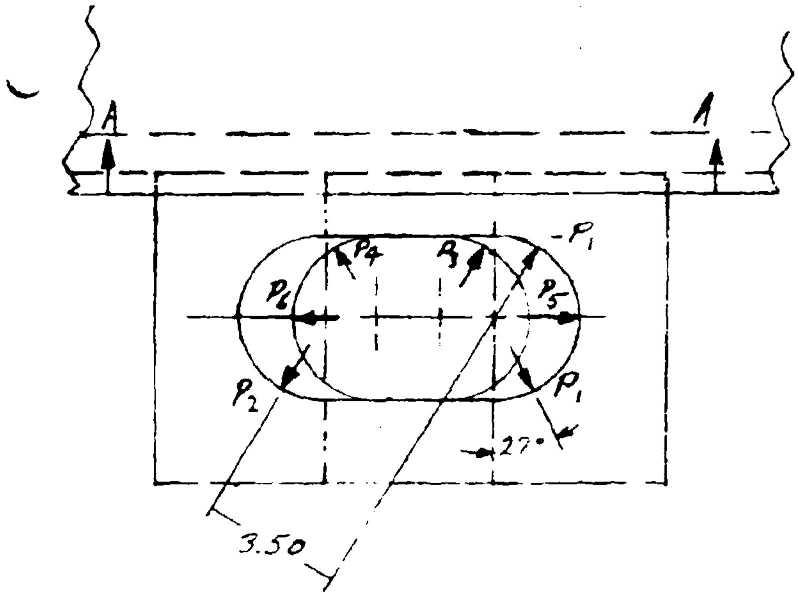
$$f_s = \frac{q}{2t} = \frac{37{,}400}{2 \times .90} = 20{,}700 \text{ PSI}$$

$F_{SU} = 64\% \times 70{,}000 = 45{,}000$ PSI

$$S.F. = \frac{45000}{20700} = \underline{2.17}$$

ZAHAREE 3/2/73

6K FORKLIFT ROPS - SOCKET CHECK



USE REVERSE LOADS. FROM PGS. 1, 7:

DUE TO P_X,

$P_5 = 14,750$ #

DUE TO P_Y,

$P_1 = \frac{14750}{2 \times \cos 27°} = 8,280$ #

$P_2 = 8,280$ #

DUE TO P_Z,

$P_N = \frac{31,700}{\sin 7° \times 2} = 130,000$ #

DUE TO M_X,

$P_1 = \frac{675,000}{8.0 \times 2 \times \cos 27°} = 47,300$ #

$P_2 = 47,300$ #

$P_3 = 47,300$ #

$P_4 = 47,300$ #

DUE TO M_Y,

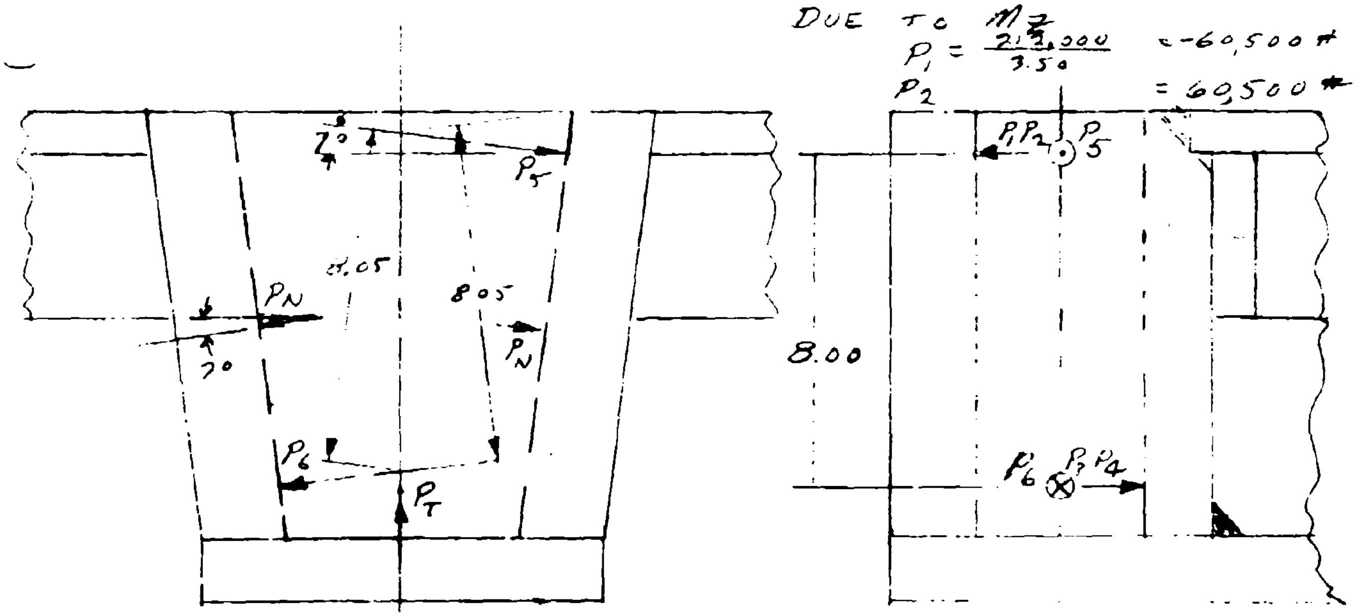
$P_5 = \frac{675,000}{8.05} = 83,800$ #

$P_6 = 83,800$ #

DUE TO M_Z,

$P_1 = \frac{212,000}{3.50} = -60,500$ #

$P_2 = 60,500$ #



SUMMING LOADS:

$P_1 = 8,280 + 47,300 - 60,500 = -4,900$ #

$P_2 = 8280 + 47,300 + 60,500 = 116,000$ #

$P_3 = 47,300$ #

$P_4 = 47,300$ #

$P_5 = 14,750 + 83,800 = 98,600$ #

$P_6 = 83,800$ #

$P_N = 130,000$ #

$P_T = (98600 + 83800) \sin 7° = 22,200$ #

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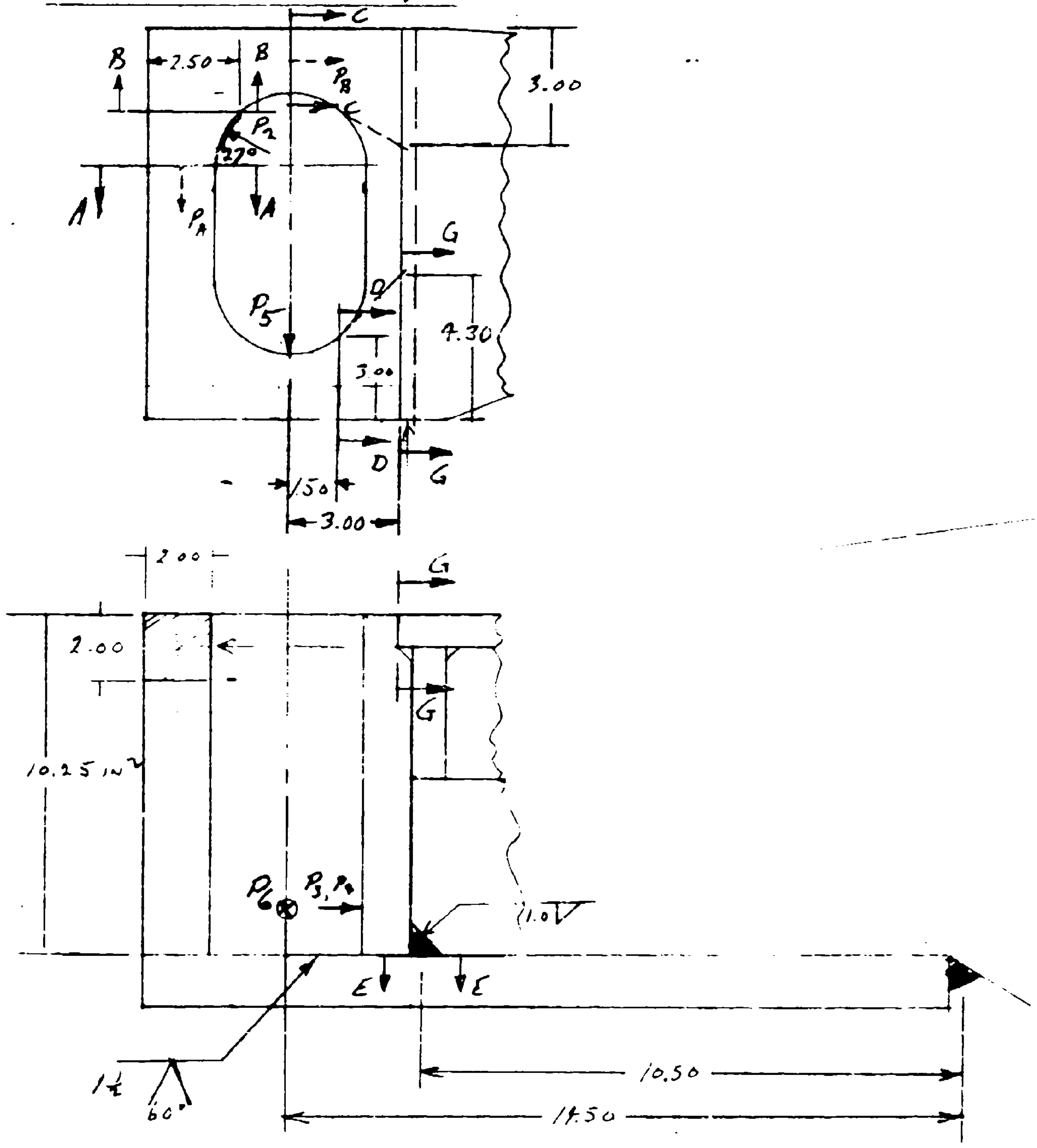
3/20/73

6K FORKLIFT ROPS

SOCKET CHECK



6K FORKLIFT ROPS

SECTION A-A (PG 11)

$P_2 = 116{,}000\ \#$ (PG. 9)

$P_A = 116{,}000 \sin 27° = 52{,}700\ \#$

$A_{AA} = 2.00 \times 2.00 = 4.00\ IN^2$

$f_T = 52{,}700 / 4.00 = 13{,}200$ PSI

$P_N = 130{,}000\ \#$ (PG. 9)

$A_{TENS} = 2.00 \times 10.25 = 20.50\ IN^2$

$f_{T_N} = 130{,}000 / 20.50 = 6{,}300$ PSI

$F_{TY} = 38{,}000$ PSI

$$S.F._Y = \frac{38000}{13{,}200 + 6{,}300} = 1.95$$

SECTION B-B

$P_B = 116{,}000 \cos 27° = 103{,}000\ \#$

$A_{B-B} = 2.50 \times 2.00 = 5.00\ IN^2$

$f_S = \frac{103{,}000}{5.00} = 20{,}600$ PSI

$f_{T_N} = 6{,}300$ PSI (REF. ABOVE)

$F_{SU} = 64\% \times 70{,}000 = 45{,}000$ PSI

$R_{TY} = \frac{6.3}{38} = .17 \qquad R_S = \frac{20.6}{45} = .46$

$$S.F_Y = \frac{1}{.17 + .46} = 2.04$$

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6K FORKLIFT ROPS

SOCKET CHECK – SECTION C-C (PG. 10)

$P_B = 103{,}000\ \#$ (PG 11)

$A_{C-C} = \underbrace{(2.00 \times 2.00)}_{\text{SOCKET}} + \underbrace{(1.50 \times 1.00)}_{\text{GUSSET}} = 5.5\ \text{IN}^2$

$f_T = \frac{103000}{5.5} = 18{,}700\ \text{PSI}$

DUE TO P_N, $f_{TN} = 6{,}300$ PSI (PG. 11)

$F_{TY} = 38000$ PSI

$\underline{S.F._Y} = \frac{38000}{18{,}700 + 6300} = \underline{\underline{1.52}}$

SECTION D-D (PG 10)

$P_5 = 98{,}600\ \#$ (PG. 9)

$M = 1.5 \times 98{,}600 = 150{,}000$ IN#

ASSUME 2 IN EFFECTIVE.

$f_b = \frac{6 \times 150{,}000}{2\ (2.50)^2} = 72{,}000$ PSI

DUE TO P_N, $f_{TN} = 6{,}300$ PSI

$R_b = \frac{72000}{1.5 \times 70000} = .69$

$R_T = \frac{6300}{70000} = .09$

$S.F._U = \frac{1}{.69 + .09} = 1.30$

ADDED GUSSETS IMPROVE S.F. (PG. 16)

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6K FORKLIFT ROPS

SECTION E-E (PG. 10)

$P_3 = P_4 = 47{,}300$ # $\quad P_6 = 83{,}800$ # (PG. 9)

$P_5 = (47{,}300 + 47{,}300) \cos 27° = 84{,}000$ #

$A_5 = \overset{6.72}{(1.00 \times .707 \times 9.50)} + \overset{22.5}{(2 \times 7.5 \times 1.5)} = 29.2 \text{ IN}^2$

$f_5 = \dfrac{84000}{29.2} = 2{,}900$ PSI

DUE TO P_6,

$P_5 = \dfrac{14.56 \times 83800}{10.50} = 116{,}000$ #

$A_5 = 1 \times .707 \times 9.5 = 6.72 \text{ IN}^2$

$f_5 = \dfrac{116{,}000}{6.72} = 17{,}300$ PSI

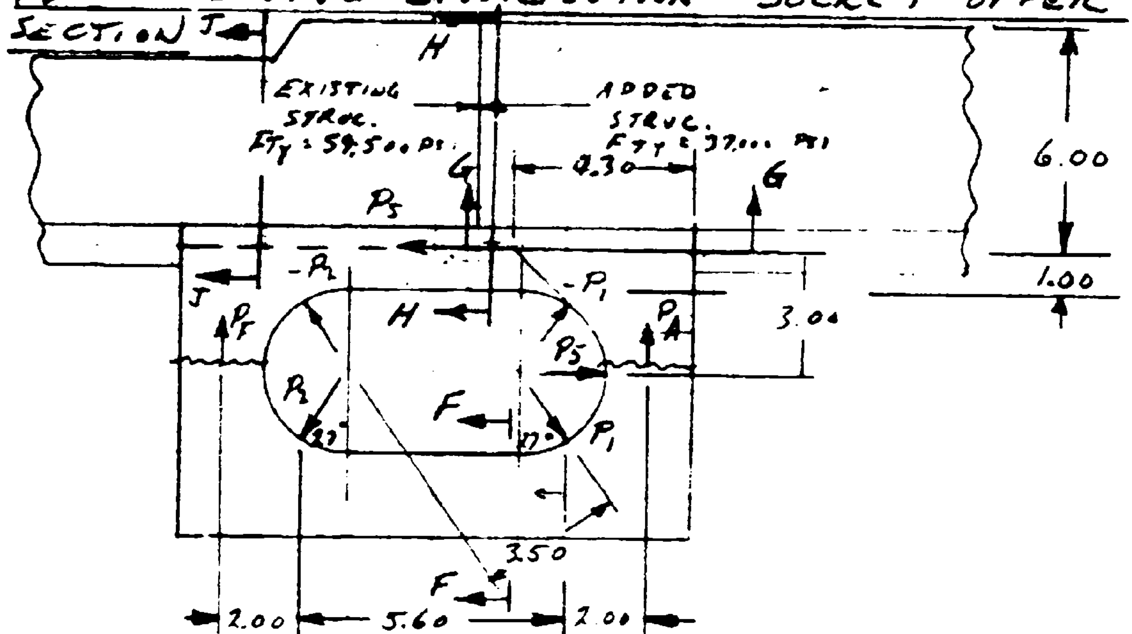
$F_{S_U} = 45{,}000$ PSI (PG. 11)

$\underline{S.F.} = \dfrac{45000}{2{,}900 + 17{,}300} = \underline{\underline{2.23}}$

20,200

6K FORKLIFT ROPS

PURE BENDING DISTRIBUTION - SOCKET UPPER SECTION



APPLIED LOADS: $P_1 = -4{,}900$ #
$P_2 = 116{,}000$ #
$P_5 = 98{,}600$ #
(PG. 9)

P_5 REACTED AT P_5. RESULTING MOMENT, M,
$= 3.00 \times 98{,}600 = 296{,}000$ IN#

MOMENT REACTED AT P_1 & $-P_2$

$$P_1 = \frac{296{,}000}{3.5} = 84{,}500 \text{ \#}$$
$$P_2 = -84{,}500 \text{ \#}$$

SUMMING LOADS: $P_1 = -4900 + 84500 = 80{,}000$ #
$P_2 = 116{,}000 - 84500 = 31{,}500$ #

$$P_A = \left[2.00(31{,}500 \cos 27°) + 7.60(80{,}000 \cos 27°)\right] / 9.60$$
$$= 62{,}300 \text{ \#}$$

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3/21/73
6K FORKLIFT ROPS

SECTION F-F (PG. 14)

$P_A = 62,300$ #
$P_1 = 84,500$ #

ASSUME P_A & LATERAL COMPONENT OF P_1 FORM A COUPLE.

$M = 2.00 \times 62,300 = 125,000$ IN#

ASSUME EFFECTIVE HEIGHT AT F-F = 3.00 IN FOR BENDING.

$f_b = \frac{6M}{bt^2} = \frac{6 \times 125000}{3.00 \times \overline{2.00}^2} = 62,500$ PSI

$P_T = P_1 \sin 27° = 84,500 \sin 27° = 38,300$ #

$A_T = 4.00$ IN² (PG. 11)

$f_T = 38300 / 4.00 = 9600$ PSI

$f_{TN} = 6300$ PSI

$R_{T_U} = \frac{9600 + 6300}{70\,000} = .227$

$R_{B_U} = \frac{62500}{1.5 \times 70000} = .595$

$\underline{S.F._U} = \frac{1}{.227 + .595} = \underline{\underline{1.22}}$

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SECTION G-G (PG 10)

$P_5 = 98,600$ # (PG. 9)

$M_{GG} = 3.00 \times 98,600 = 296,000$ IN #

1 INCH WELD AT SECTION G-G, 4.70 IN. LONG.

$$f_b = \frac{6M}{bt^2} = \frac{6 \times 296,000}{1.00 \times \overline{4.3}^2} = 96,000 \text{ PSI}$$

$$S.F. = \frac{.50 \times 70000}{96,000} = 1.07$$

EXCESSIVE! ADD 5×5×1 GUSSETS.

$$f_b = \frac{6 \times 296,000}{1.00 \times \overline{9.0}^2} = 22,000 \text{ PSI}$$

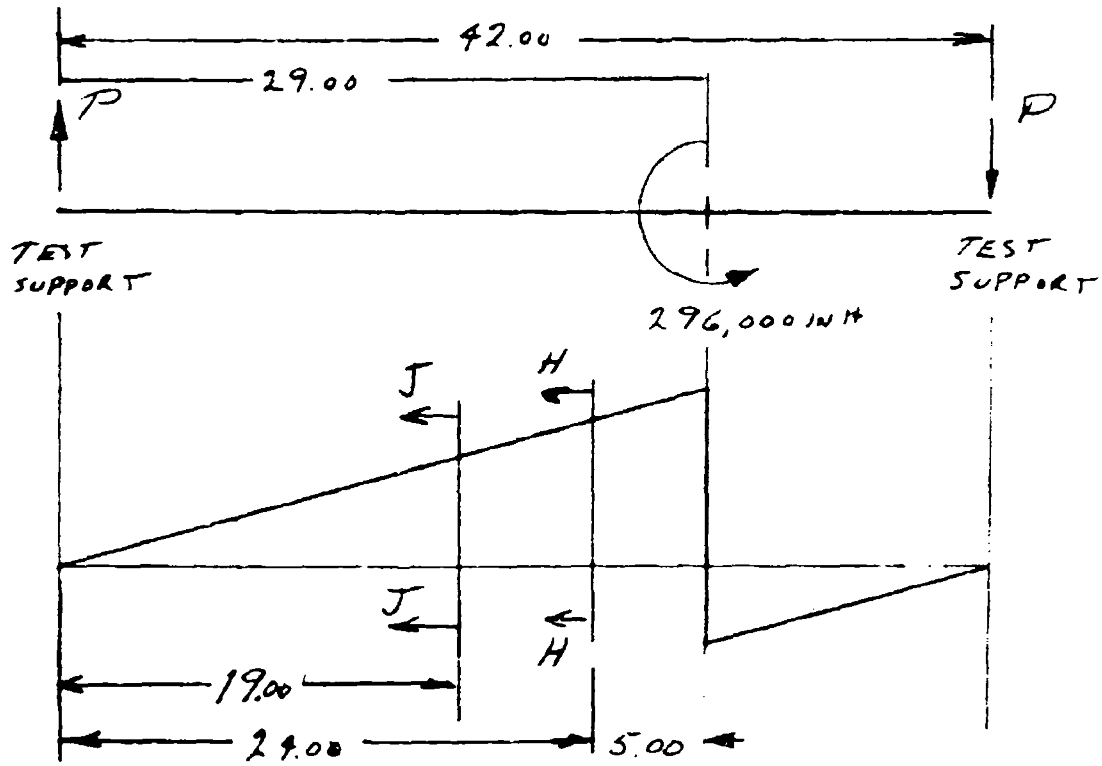
$F_{TY} = 38,000$ PSI

$$S.F._Y = \frac{38000}{22000} = \underline{\underline{1.73}}$$

6K FORKLIFT ROPS

SECTION H-H (PG. 14)

$$M = 296,000 \text{ IN}\# \quad (M_Z)$$
$$P = 296,000 / 42.00 = 7050\#$$



$$M_{H-H} = 24 \times 7050 = 169,000 \text{ IN}\#$$

$$f_b = \frac{6M}{bt^2} = \frac{6 \times 169,000}{1.00 \times 7.00^2} = 20,800 \text{ PSI}$$

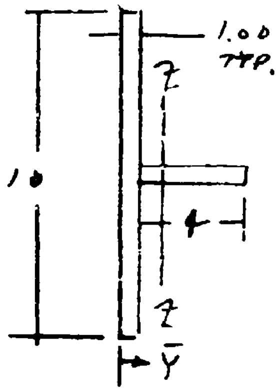
$$F_{TY} = 37,000 \text{ PSI}$$

$$\underline{S.F._Y} = \frac{37000}{20800} = \underline{\underline{1.73}}$$

6K FORKLIFT ROPS

SECTION J-J (FIGS 14, 17)

$M_{JJ} = 19 \times 7050 = 134{,}000$ IN#



$I_{ZZ} = 24 \text{ IN}^4$
$\bar{Y} = 1.2$ IN

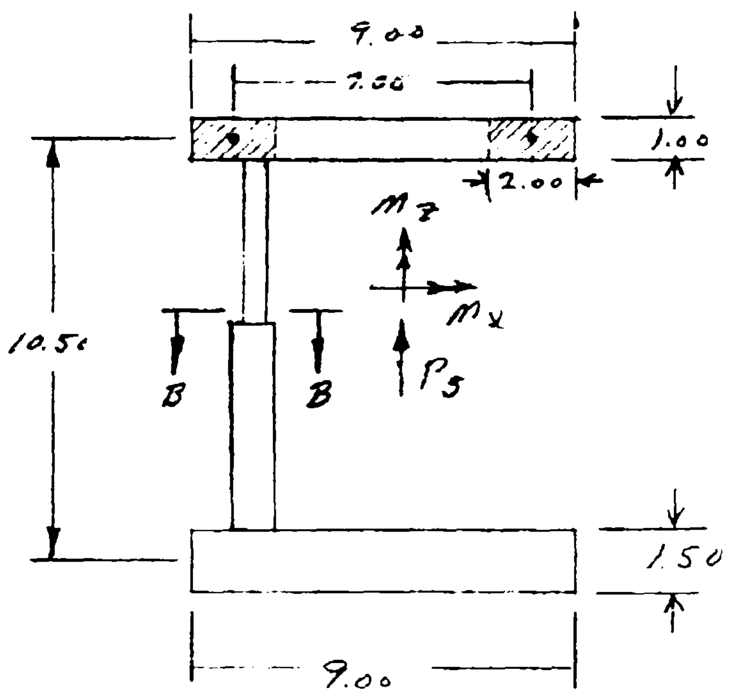
$f_b = \dfrac{134000 \times 3.8}{24} = 21{,}000$ PSI

$F_{TY} = 54{,}500$ PSI

$S.F._y = \dfrac{54500}{21000} = \underline{\underline{2.60}}$

6K FORKLIFT ROPS

SECTION A-A (REF SKETCH, PG. 9)



ASSUMED EFFECTIVE SECTION.

ASSUME M_Z REACTED BY CROSSBEAM & REACTED BY 7.00 IN. COUPLE AT TOP BEAM.

FROM PG. 11, M_X = 716,000 IN #

M_Z = 229,000 IN #

P_{S_V} = P_Z − 28,000 = 67,200 − 28000
= 39,200 #

UPPER BEAM CHECK:

DUE TO M_X, $P_T = \frac{716,000}{10.50}$ = 68,000 #

f_T = 68000 / 4.00 × 1.00 = 17,000 PSI

DUE TO M_Z, $P_T = \frac{229,000}{7.00}$ = 32,700 #

f_T = 32,700 / 2.00 × 1.00 = 16,300 PSI

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GK FORKLIFT ROPS

SECTION A-A (CONT'D)

$$\Sigma f_T = 17{,}000 + 16{,}300 = 33{,}000 \text{ PSI}$$

$$F_{TY} = 36{,}000 \text{ PSI}$$

$$\underline{S.F.} = \frac{36{,}000}{33{,}000} = \underline{1.09}$$

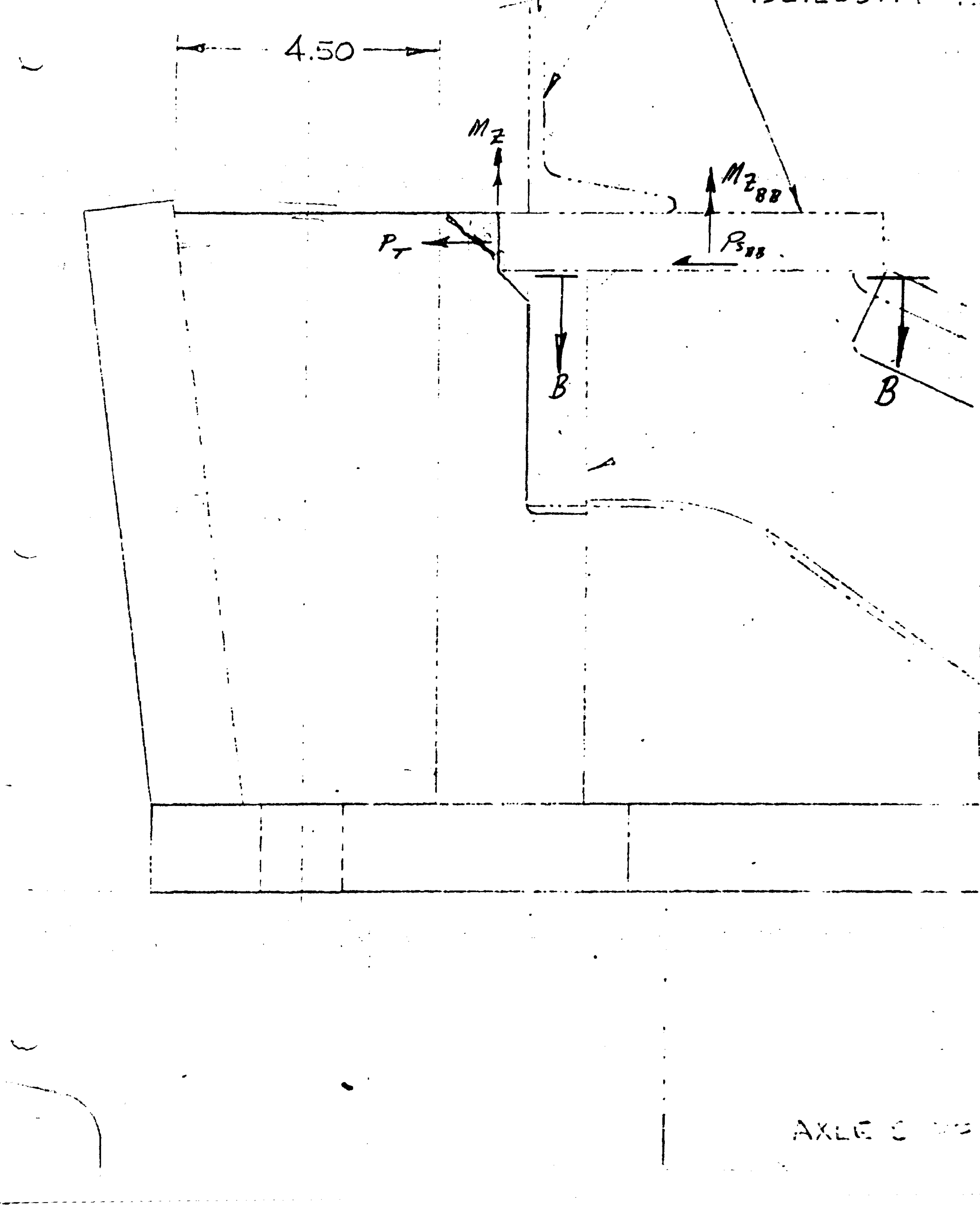
SECTION B-B

BEAM SHEAR CHECK

$$q = \frac{P_S}{10.51} = \frac{38{,}200}{10.51} = 3700 \ \#/\text{IN}$$

$$f_S = \frac{3700}{.50} = 7400 \text{ PSI}$$

2/27/73
6 K ROPS



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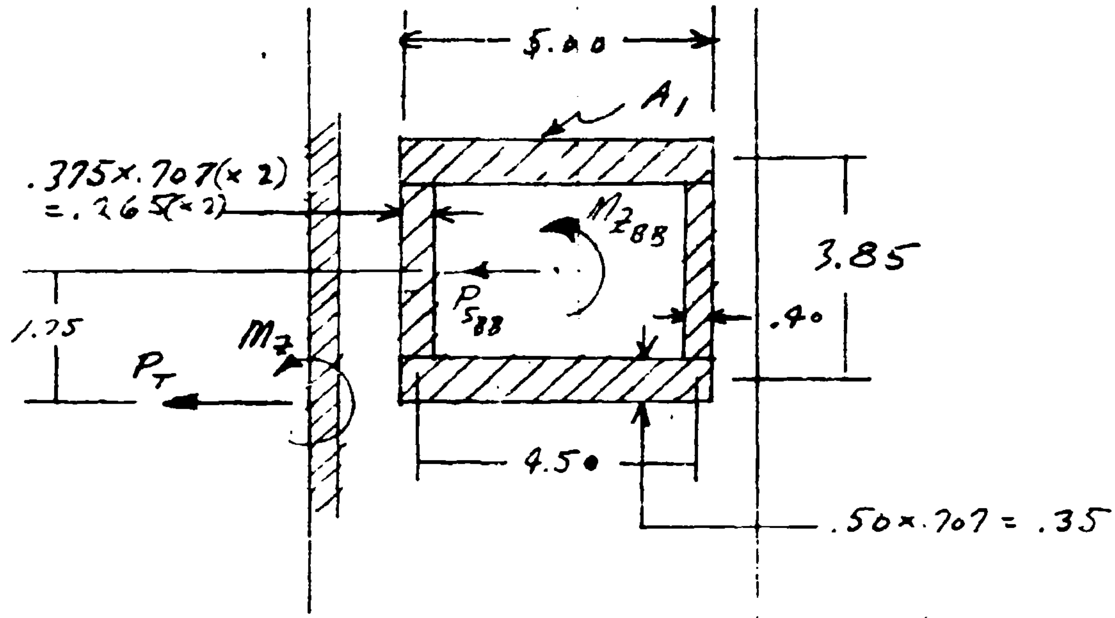
6K FORKLIFT ROPS

SECTION B-B (PG 14)



$P_T = 68,000$ # DUE TO M_x (PG. 12)

$M_Z = 229,000$ IN # (PG. 12)

$P_{S_{B\text{-}B}} = P_T = 68000$ #

$M_{Z_{BB}} = 229,000 - 1.75\overset{119,000}{(68,000)} = 110,000$ IN

$$f_S = \frac{P_{S_{BB}}}{A_S} + \frac{M_{Z_{BB}}}{2At}$$

$A_S = 2[(4.50 \times .35) + (3.85 \times .265)] = 5.2$

$A = 4.50 \times 3.85 = 17.3$ IN^2

$$f_S = \overset{13,100}{\frac{68000}{5.2}} + \overset{9,100}{\frac{110,000}{2 \times 17.3 \times .35}} = 22,200 \text{ PSI}$$

$F_{S_U} = 54,500$ PSI (EXIST. X BEAM)

$$S.F. = \frac{54,500}{22,200} = \underline{2.45}$$

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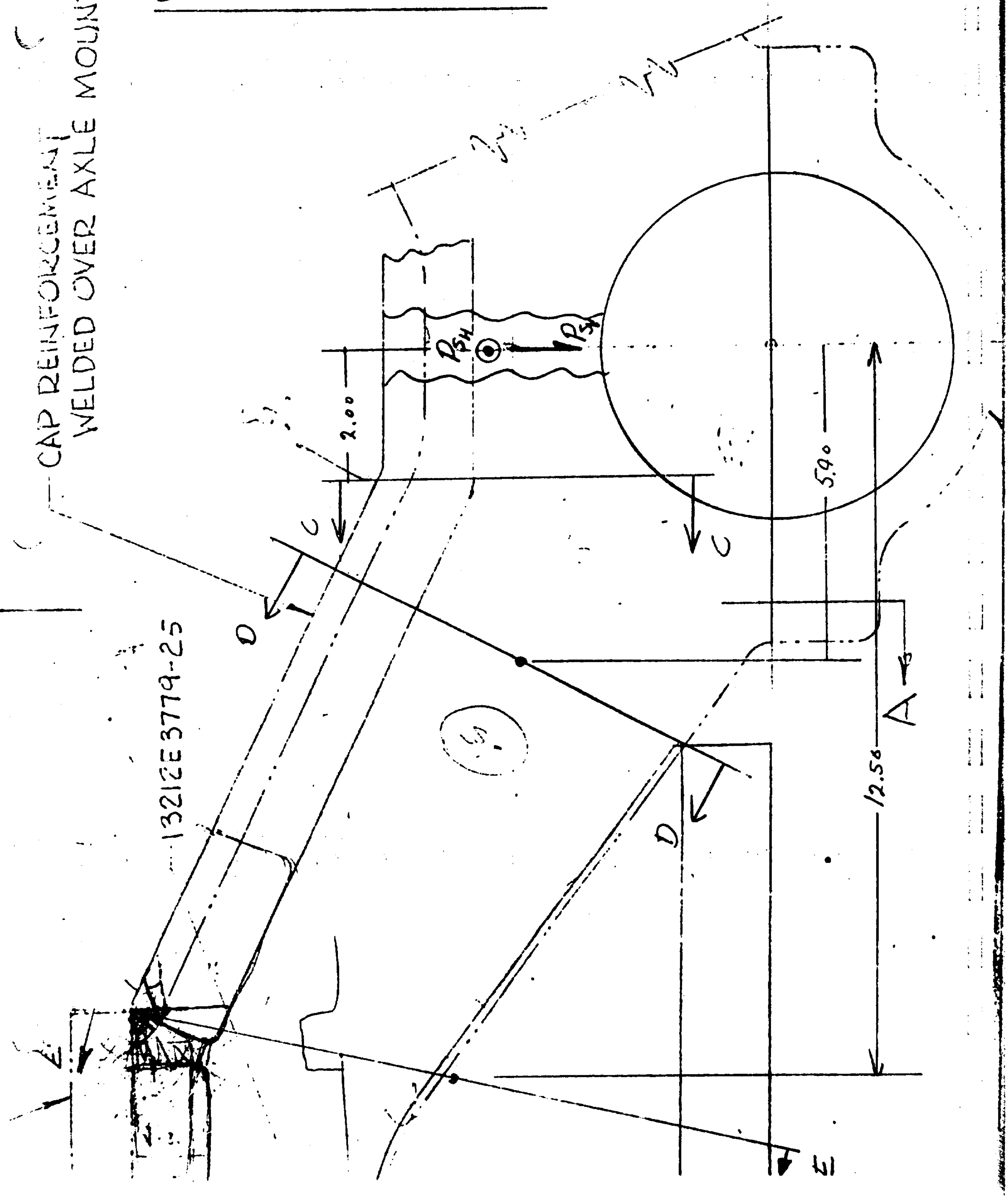
6K FORKLIFT RODS



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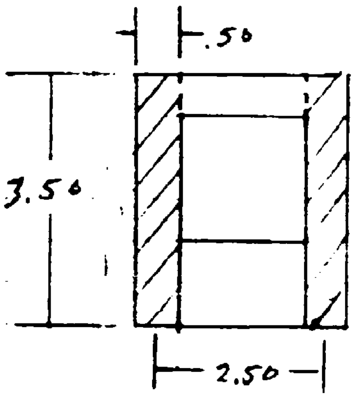
6 K FORKLIFT ROPS

SECTION C-C (PG. 16



$P_{S_V} = 39{,}200$ # (PG. 12)

$P_{S_H} = 25{,}600 - 13{,}000 = 12{,}600$ #

$M_{HOR.} = 2 \times 39{,}200 = 80{,}000$ IN #

$f_{b_{HOR}} = \dfrac{6 \times 80{,}000}{1.00 \times \overline{3.5}^2} = 40{,}000$ PSI

$M_{VERT} = 2 \times 12{,}600 = 25000$ IN #

$f_{b_{VERT}} = \dfrac{M}{A} = \dfrac{25000}{2.5 \times 3.50 \times .50} = 6000$ PSI

$F_{TY} = 55{,}000$ PSI

$\underline{\underline{S.F.}} = \dfrac{55000}{40{,}000 - 6000} = \underline{1.20}$

(CONSERVATIVE CHECK)

SECTION D-D (PG 12)

WELD CHECK $P_{S_V} = 39{,}200$ # (PG 12)

$P_{WELD} = \dfrac{5.40 \times 39{,}200}{6.50} = 32{,}500$ #

$A_{WELD} = 5.00 \times .5 = 2.5$ IN²

$f_T = \dfrac{32500}{2.5} = 13{,}000$ PSI

$F_{TY} = 36\,000$ PSI

$\underline{\underline{S.F.}} = \dfrac{36000}{13{,}000} = \underline{2.70}$

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6K FORKLIFT

SECTION EE (PG. 16)

WELD CHECK $P_s = 39200\#$ (PG 12)

$$P_{WELD} = \frac{12.50 \times 39200}{9.50} = 52000\#$$

$$A_{WELD} = .50 \times 3.00 = 1.5\ IN^2$$

$$f_t = \frac{52000}{1.5} = 35,000\ PSI$$

$$F_{TU} = 36,000\ PSI$$

$$S.F. = \frac{36000}{35000} = 1.03$$

(CONSERVATIVE CHECK)

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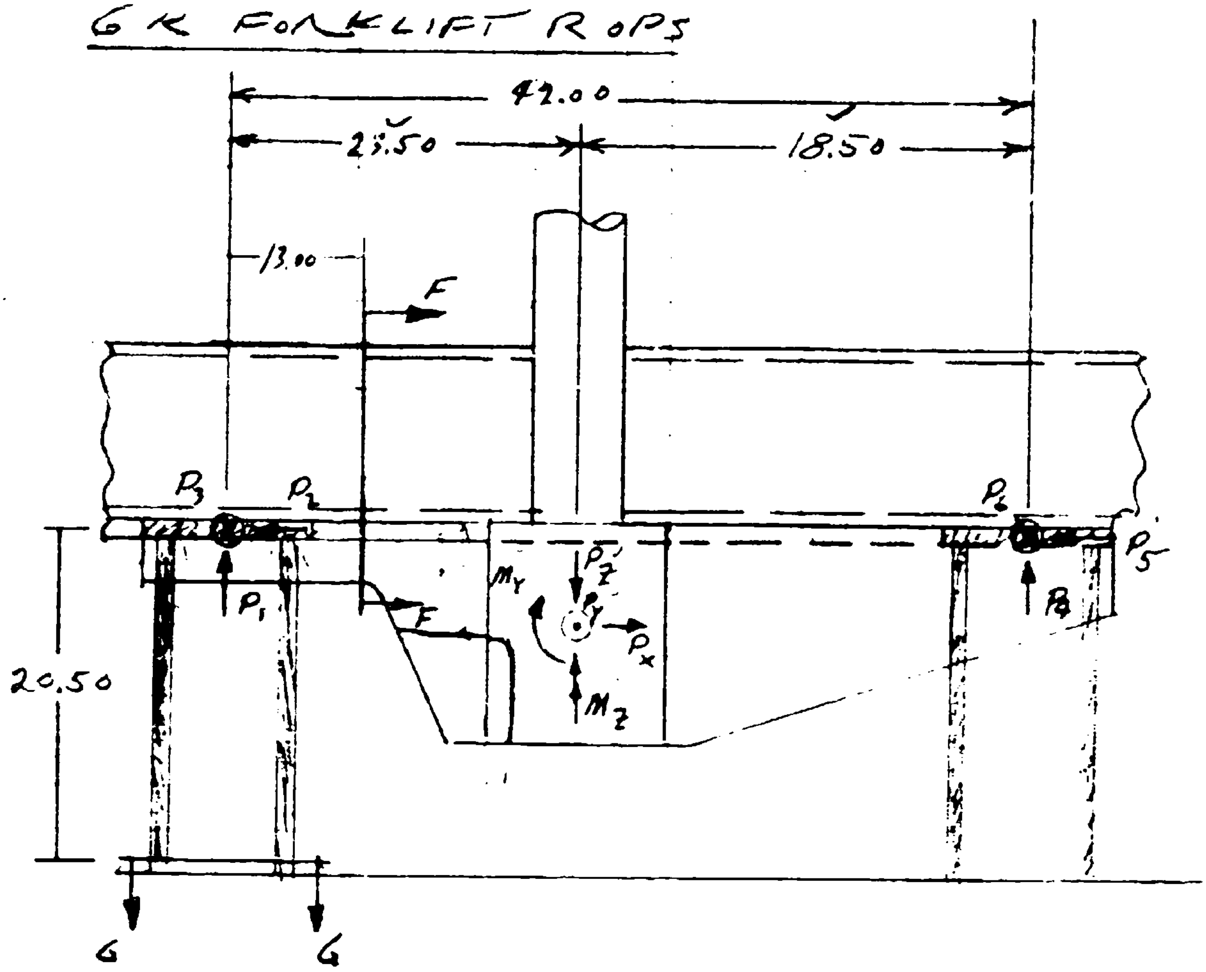
6K FORKLIFT ROPS



FROM PG. 11, $P_X = 25{,}600$ #

$P_Y = 13{,}000$ #

$P_Z = 67{,}200$ #

$M_Y = 625{,}000$ IN #

ASSUME STRUCTURE REACTS $M_Z = 229{,}000$ IN #

$P_1 = (18.50 \times 67{,}200 - 625{,}000)/42.00 = 14{,}700$ #

$P_2 = 25{,}600/2 = 12{,}800$ #

$P_3 = (18.50 \times 13{,}000 + 229{,}000)/42.00 = 11{,}200$ #

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<u>6K FORKLIFT ROPS</u>

$$P_4 = (23.50 \times 67{,}200 + 625000)/42.00 = 52{,}50\#$$

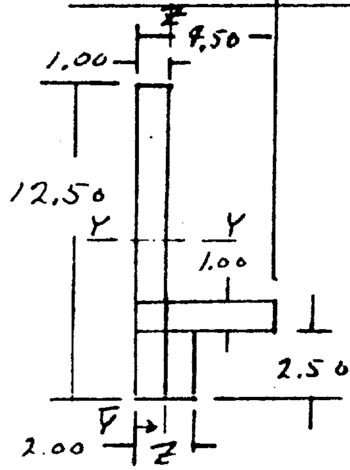
$$P_5 = 25{,}600/2 = 12{,}800\#$$

$$P_6 = (23.50 \times 13{,}000 - 229{,}000)/42.00 = 1{,}800\#$$

IF STRUCTURE DOESN'T REACT M_Z,

$$P_6 = (23.50 \times 13000)/42.00 = 7{,}280\#$$

<u>SECTION F-F</u>



$A = 18.5\ \text{IN}^2$
$I_{ZZ} = 19\ \text{IN}^4$
$\bar{Y} = 1.06$

$$M_{YY} = 13.00 \times 14{,}700 = 191{,}000\ \text{IN}\#$$

$$M_{ZZ} = 13.00 \times 11{,}200 = 146{,}000\ \text{IN}\#$$

$$f_{bYY} = \frac{6 \times 191{,}000}{1.00(12.50)^2} = 7{,}300\ \text{PSI}$$

$$f_{bZZ} = \frac{146{,}000 \times 3.44}{19} = 26{,}500\ \text{PSI}$$

$$F_{TY} = 36{,}000\ \text{PSI}$$

$$\underline{\text{S.F.}} = \frac{36000}{26500} = \underline{1.36}$$

$f_{bZZ} \approx 20{,}000$ PSI INCLUDING CHANNEL SECTION

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6 K FORKLIFT ROPS

WELD CHECK AT P_3 (PG. 19)

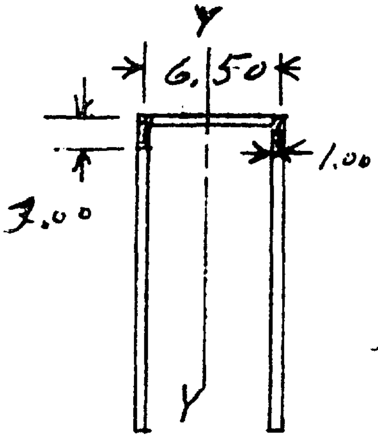
$P_3 = 11,200 \#$

$A = 9 \times .50 \times 2 = 9 \text{ IN}^2$

$f_T = \frac{11,200}{9} = 1200 \text{ PSI}$

$MS = \text{HIGH}$

SECTION G-G



$M_{YY} = 12,800 \times 20.5 = 262,000 \text{ IN}\#$

$P_T = \frac{262\,000}{6.5} = 40,000 \#$

ASSUME 3" EFFECTIVE

$f_T = \frac{40,000}{3.00 \times 1.00} = 14,000 \text{ PSI}$

$F_{TY} = 36,000$

$S.F. = \frac{36000}{14000} = 2.5$

WELD CHECK FOR P4

$P4 = 52,500 \#$ (PG. 19)

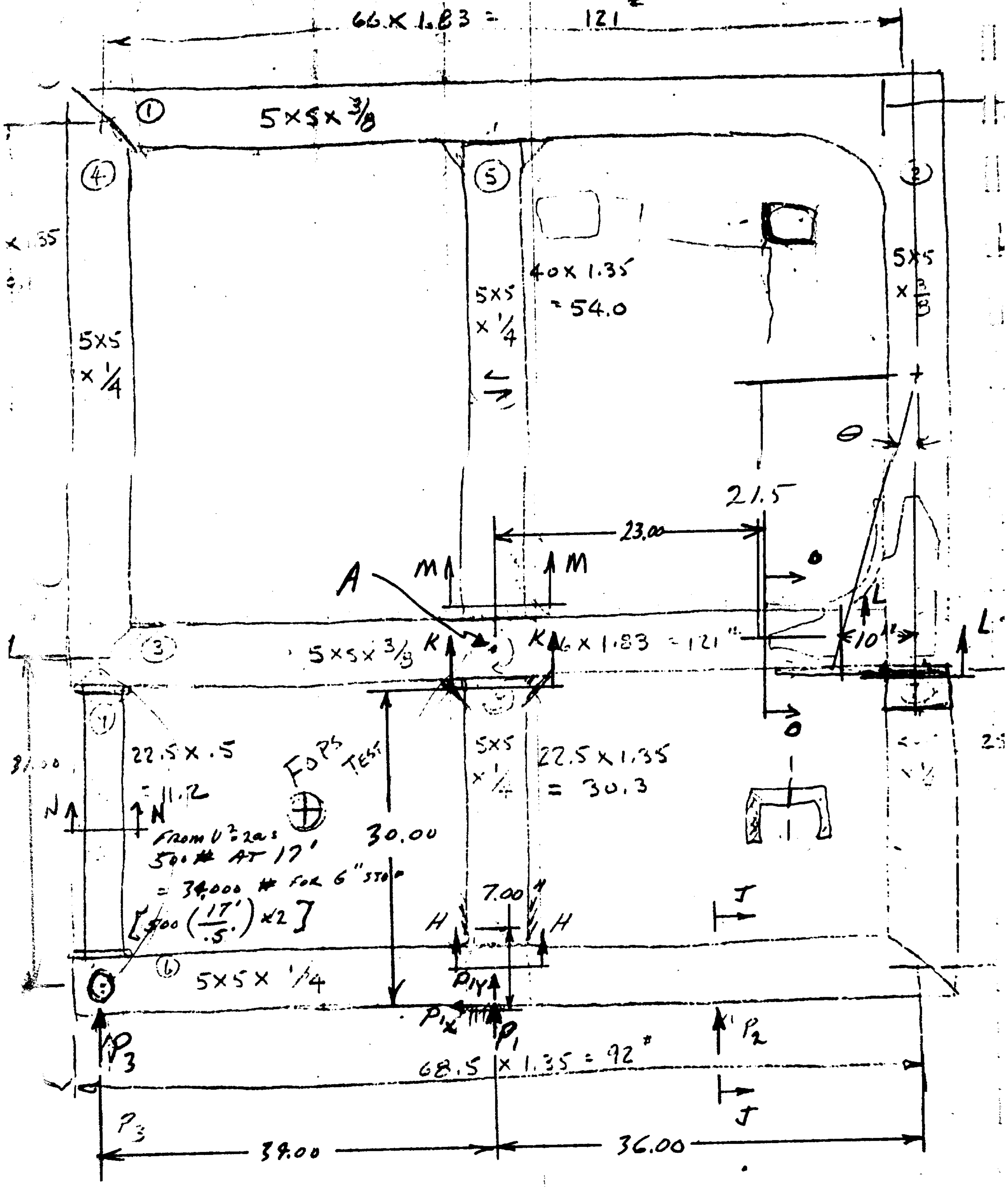
$A_S = 10 \times .5 \times .707 = 3.5 \text{ IN}^2$

$f_S = 52,500 / 3.5 = 15\,000 \text{ PSI}$

$F_{SU} = 37,000 \text{ PSI}$

$S.F._U = \frac{37000}{15000} = 2.47$

6K FORKLIFT, ROPS

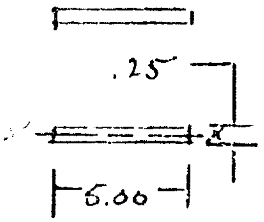


ZAHAREE
2/28/73

6K FORKLIFT ROPS

SECTION H-H

WALL COLUMN CHECK



$$P_1 = 26{,}000\ \#$$

$$P_{COLUMN} = 26{,}000 / 2 = 13{,}000\ \#$$

$I_{xx} = .0065\ IN^4$

$A = 1.25\ IN^2$

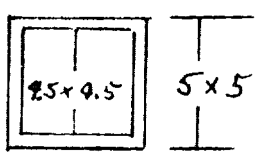
$$P_{ALLOW_{I}} = \frac{\pi^2 E I}{L^2} = \frac{\pi^2 \times 29\times10^6 \times .0065}{7.00^2}$$

$$= 38\ 000\ \#$$

$$P_{ALLOW_{II}} = F_{TY} \cdot A = 36{,}000 \times 1.25 = 45\ 000\ \#$$

$$\underline{S.F.} = \frac{38\ 000}{13\ 000} = \underline{2.9}$$

SECTION J-J



$I = 17.9\ IN^4$

$$P_2 = 26{,}000\ \#$$

$$M_{JJ} = \frac{P_2}{2} \times 18 = 9 \times 26\ 000 = 234{,}000\ IN\#$$

$$f_b = \frac{234{,}000 \times 2.5}{17.9} = 33{,}000\ PSI$$

$$\underline{S.F.} = \frac{36{,}000}{33\ 000} = \underline{1.09}$$

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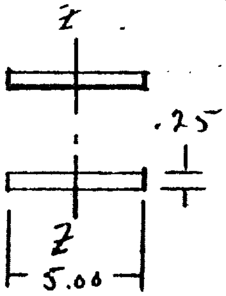
2/28/73

6K FORKLIFT ROPS

SECTION K-K



$P_1 = 26,000$ #

ASSUME 10" LONG. MOVEMENT AT POSTS.

FROM $\delta = R\theta$, $\theta = \frac{\delta}{R} = \frac{10}{21.5} = .465$ RAD

$= 26°$

AS A RESULT, P_1 WILL BE APPLIED AT 26°

$P_{1x} = 26000 \sin 26° = 11,400$ #

$P_{1y} = 26000 \cos 26° = 23,300$ #

$M_{ZZ} = \frac{30 \times 11,400}{2} = 170,000$ IN #

$f_b = \frac{6 \times 170,000}{.50 (5)^2} = 82,000$ PSI

EXCESSIVE! ASSUME FULL M_{ZZ} IS REACTED AT L-L

$M_{L-L} = 30 \times 11,400 = 340,000$ IN #

$I_{L-L} = I_{ZZ} = 17.9$ (PG. 23)

$f_b = \frac{340,000 \times 2.5}{17.9} = 47,500$ PSI

EXCESSIVE! ADD $4\frac{1}{2} \times 4\frac{1}{2} \times \frac{3}{8}$ GUSSETS AT K-K OR ADD DIAGONAL.

$A_{DIAGONAL} = \frac{11,400 \times 2}{\cos 91° \times 36000} = .84$ IN²

$f_b = \frac{6 \times 170,000}{.375 \times 74^2} = 14,000$ PSI

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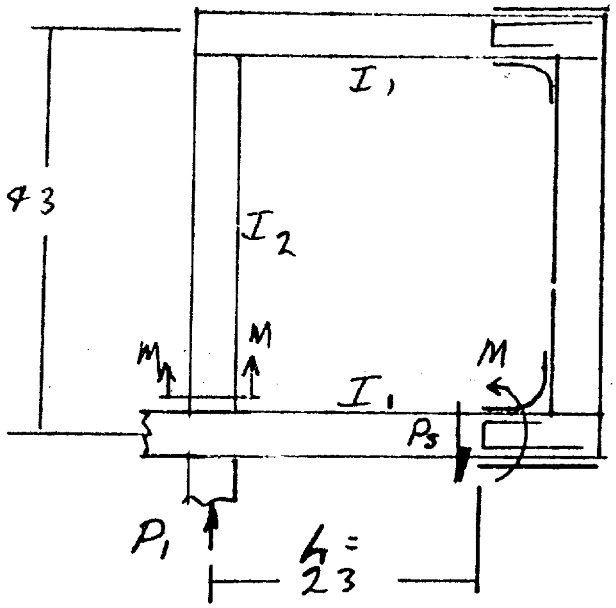
2/28



$$M = \frac{Ph}{2}\left(\frac{3C}{E} - 1\right)$$

GRIFFEL, PG 276, #16

$$C = \frac{I_2}{I_1}\left(\frac{h}{L}\right) \qquad I_2 = \frac{5^4 - 4.5^4}{12} = 17.9 \text{ IN}^4$$

$$I_1 = \frac{5^4 - 4.25^4}{12} = 25$$

$$C = \frac{17.9}{25}\left(\frac{23}{43}\right) = .383$$

$$E = 1 + 6(.383) = 3.3$$

$$M = \frac{Ph}{2}\left(\frac{3 \times .383}{3.3} - 1\right) = .65\left(\frac{Ph}{2}\right)$$

$$= .65\left(\frac{26{,}000 \times 23}{2}\right) = 195{,}000 \text{ IN\#}$$

ZAHARCZ
2/78

SECTION M-M PLS 22, 25

$P_1 = 26,000$ #

$P_5 = 13,000$ # PL. 25

$M_{MM} = 13,000 \times 23 - 195000 = 105,000$ IN# (300,000)

$f_b = \frac{6M}{bt^2} = \frac{6 \times 105,000}{.50 \times 5^2} = 50,000$ PSI

EXCESSIVE! USE GUSSETS AT M-M

SECTION N-N

$P_3 = 26,000$ #, $I = 1.53$ IN^4

$P_{ALLOW} = \frac{\pi^2 \times 29 \times 10^6 \times 1.53}{31.00^2} = 450,000$ #

AT PT A DUE TO $P_3 = 26,000$#:

$M_A = \frac{26000}{2} \times 34.00 = 440,000$ IN#

ASSUME $\frac{1}{2}$ OF M_A IS ON SECTION M-M

$M_{M\text{-}M} = \frac{440,000}{2} = 220,000$ IN#

USING GUSSETS, BASIC SECTION CHECK:

$f_b = \frac{220,000 \times 2.5}{17.9} = 30,000$ PSI

$F_{BY} = 36,000$ PSI $\times 1.22 = 44,000$

$F.S._Y = \frac{44000}{30000} = 1.20$

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2/28/73

6K FORKLIFT ROPS

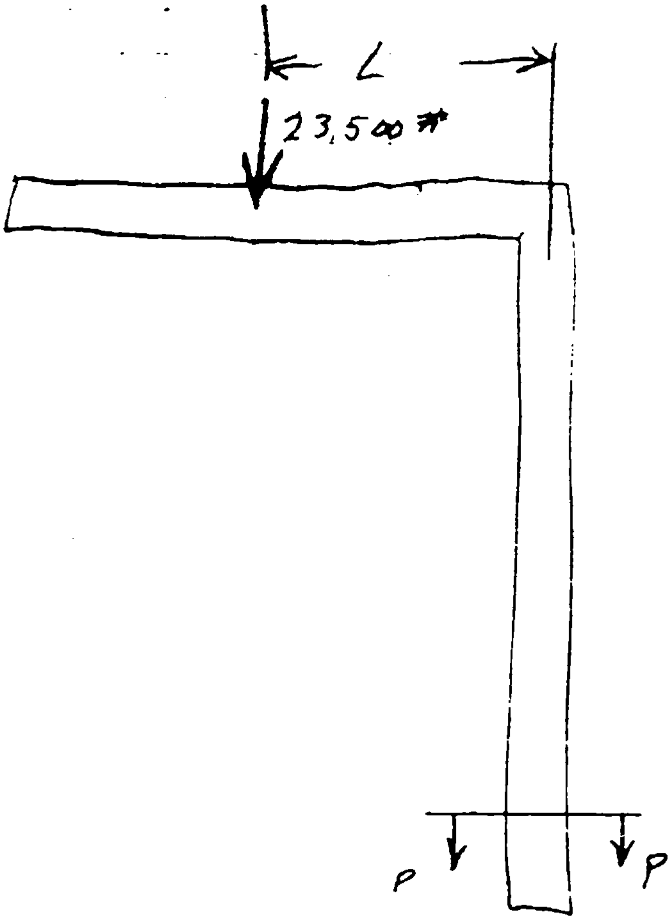
SECTION O-O

$$M_{OO} = 220,000 + \overset{300,000}{13,000(23.00)} = 520,000 \text{ IN \#}$$

$$f_b = \frac{520,000 \times 2.5}{25} = 52,000 \text{ PSI}$$

$$F_{TU} = 55000 \text{ PSI}$$

$$F.S._U = \frac{55000 \times 1.2}{52000} = 1.27$$



$L = 33.5'' + 3''\ \text{DEFL} = 36.5''$

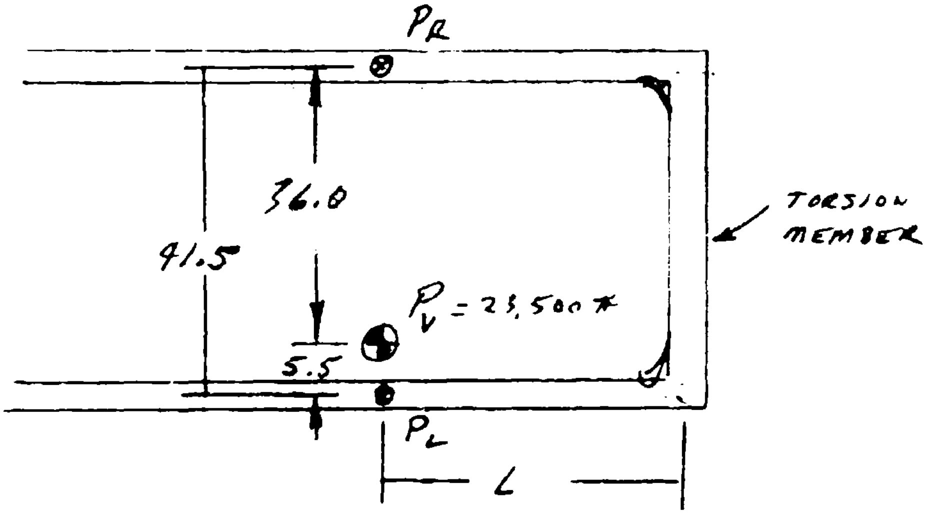
$M_{PP} = 36.5 \times 23{,}500/2 = 428{,}000\ \text{IN\#}$

$f_b = \dfrac{428{,}000 \times 2.5}{21.9} = 49{,}000\ \text{PSI}$

$F_{bY} = 1.14 \times 50{,}000 = 57{,}000\ \text{PSI}$

$S.F._Y = \dfrac{57}{49} = 1.16$

CHECK OFF CENTER LOAD DISTRIBUTION



$$P_L = \frac{36.0}{41.5} \times 23,500 = 20,400 \text{ \#}$$

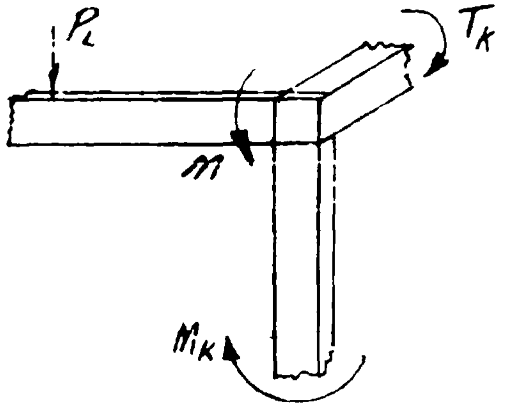
$$P_R = \frac{5.5}{41.5} \times 23,500 = 3,100 \text{ \#}$$

$$L = 32 + \text{DEFL.} = 32 + 5.5 = 37.5 \text{ IN}$$

$$M_L = 37.5 \times 20,400 = 765,000 \text{ IN\#}$$

$$f_b = \frac{765,000 \times 2.5}{21.9} = 87,500 \text{ PSI}$$

CONSIDER CROSS COUPLING OF TORSION MEMBER.

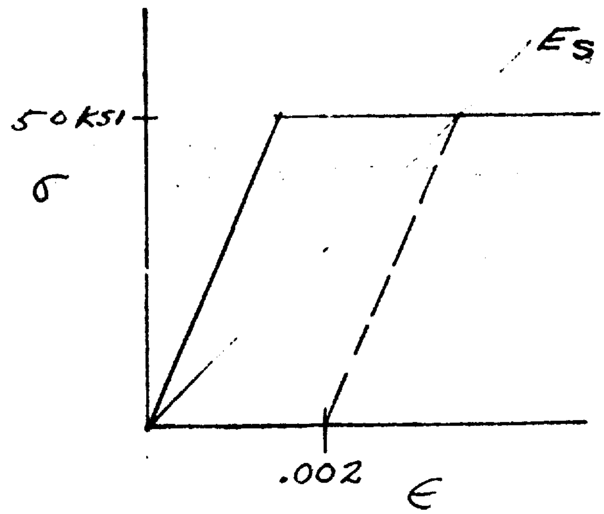


FOR $M = 10,000$ IN#,

$$\theta_{T_x} = \frac{TL}{KG} = \frac{10,000 \times 41.5}{40.2 \times 11 \times 10^6} = .00094$$

$$K_T = \frac{10,000}{.00094} = 10.6 \times 10^6 \ \frac{\text{IN\#}}{\text{RAD}}$$

ASSUME LEFT VERTICAL LEG IS AT YIELD STRESS. $F_{TY} = 50{,}000$ PSI



ELASTICLY, $\epsilon = \dfrac{\sigma}{E} = \dfrac{50}{29000} = .0017$ IN/IN

PLASTICLY, $\epsilon = .002$ IN/IN

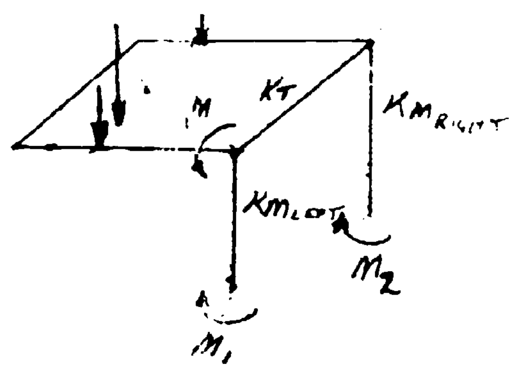
$\Sigma\ \epsilon = .0017 + .002 = .0037$ IN/IN

$E_s = \dfrac{\sigma}{\epsilon} = \dfrac{50{,}000}{.0037} = 13.5 \times 10^6$ PSI

$M = 10{,}000$ IN# (CON'T'D)

$$\theta_{M_K} = \frac{ML}{EI} = \frac{10{,}000 \times 92.5}{29 \times 10^6 \times 21.9} = .00146 \text{ RAD}$$

$$K_{M_{RIGHT}} = \frac{10.000}{.001460} = 6.85 \times 10^6 \text{ IN\#/RAD}$$



$$K_{M_{LEFT}} = \frac{13.5 \times 10^6}{29 \times 10^6} \times 6.85 \times 10^6$$
$$= 3.19 \times 10^6 \text{ IN\#/RAD}$$

$$\frac{1}{K_2} = \frac{1}{K_T} + \frac{1}{K_{M_{RIGHT}}} = \frac{1}{10.6} + \frac{1}{6.85} = .0944 + .146 = .2\cdot$$

$$K_2 = \frac{1}{.24} = 4.16 \times 10^6$$

$$K_1 = K_{M_{LEFT}} = 3.19 \times 10^6$$

SINCE K_2 BECOMES LARGER THAN K_1, EVEN LOAD DISTRIBUTION OCCURS BEFORE LEFT LEG REACHES F_{TY}.

GO TO PG. 28.

DUE TO M:

$$M_1 = \frac{6.85}{\underset{(11.01)}{6.85 + 4.16}} M = .622 \; M$$

$$M_2 = \frac{4.16}{11.01} M = .378 \; M$$

APPENDIX 6.3

DEVELOPMENT TEST RESULTS

TR-684-059

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

TEST SPECIMEN Two-post ROPS

TEST TYPE FOPS, Horizontal and Vertical Loading

TEST DATE 29 May and 6 June 1973

TEST TEMPERTATURE 96 - 106°F

LPC WORK ORDER 684-7-44

TEST RESULTS

The 6K forklift chassis was modified in accordance with LPC Drawing 299025. The chassis was mounted in the test bay in compliance with SAE Technical Report J-394A. The tiedown arrangement is shown in Drawing 299025.

The five-inch ROPS was installed on the chassis with two each 1½" bolts and torqued as for field service.

The FOPS test made use of high speed movies to ensure that the critical zone was not violated during the FOPS test. Deflection of the ROPS would be measured by a photo target grid that was mounted beyond the ROPS in view of the camera.

FOPS

Solid wooden forms representing the critical zone were installed in the ROPS to aid in the final determination of success or failure. The critical zone was installed per SAE J-397A and LPC Drawing 299025.

A 500-pound standard drop object was positioned over the ROPS, raised 17 feet and dropped. There was no violation of the critical zone.

HORIZONTAL LOADING

A load application system consisting of one 700,000-pound hydraulic ram was installed to contact the ROPS roof for horizontal loading. The test setup is shown in Figure 1.

The test operations procedure is presented on pages 5 through 8.

One fourteen-inch linear potentiometer was utilized to measure deflection at the point of load application.

The force and deflection measurements were displayed in digital format for monitoring during the test and were also recorded at each deflection increment.

A total of 40 strain measurements were recorded during the horizontal loading to monitor the ROPS deformation. The strain gage locations are shown on Drawing 299023. The strain gage data are presented in Addendum I.

In addition, 3 optical deflection measurements were taken in accordance with Drawing SK-684-118 to monitor the test progress. These deflection readings are presented on page 9.

Steel scales were installed on the ROPS and read with a surveyor's transit to measure deflection. These readings are presented on page 9.

The load was applied, as required, to produce approximate one-half inch deflection increments during the initial loading. At 3.1 inches deflection the minimum force requirement was met. At 8.0 inches, the minimum energy requirement was met and the horizontal load test was terminated. A plot of force versus deflection is shown in Figure 2 from data on page 10.

At full load and deflection, the critical zone was not violated.

VERTICAL LOAD

The load column was aligned with the geometric center of the ROPS with a load beam to distribute the load laterally across the top surface of the ROPS.

The camera target was installed and camera position was noted to calculate the deflection for each of the 6 load points. Strain gage data was also recorded and are presented in Addendum II.

The full load position is shown in Figure 3, and shows that the critical zone was not violated during the vertical test.

HORIZONTAL OVERTEST

Following compliance to SAE requirements, the horizontal load system was reinstalled. The test was performed for engineering evaluation. The test was continued until a deflection increase could be accomplished without an increase in force. The maximum recorded load was 24,000 pounds. Strain gage data were recorded but not reduced.

VERTICAL OVERTEST

To complete the test on the 6K forklift ROPS, a vertical overtest was conducted on 6 June 1973. This test was conducted for engineering evaluation. The purpose of this test was to determine the load capability of the unit before the critical zone was invaded. Strain gage data was recorded but not reduced. The test was terminated when the loading distribution plate slipped.

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
EQUIPMENT LIST

Hydraulic Ram (Horizontal)	700K, Pickens Inc. 9480-18-3683 18-inch stroke
Hydraulic Ram (Vertical)	300K, Rodgers Hydraulic, Part Number 1-150 BR-7½, 7½-inch stroke
Load Cell (Horizontal)	Ormond L-25-50K-557
Load Cell (Vertical)	Ormond L-25-50K-557
Displacement Transducers	1 each 14-inch, 3 each Starrett Dial Indicators and 3 each 18-inch scales, and 1 Bourns 2001081615 potentiometers
Data Acquisition System	Beckman 210, 84-channel Digital Data System

OPTIONAL EQUIPMENT

Strain Gages	BLH FAP-12-12 or equivalent
Thermocouple Potentiometer	
Conditioning Box Controller	

MEASUREMENT ACCURACY

The measurement systems and devices utilized in support of this test program are periodically maintained and calibrated to assure the following steady state accuracies. Instrument calibrations are traceable to the National Bureau of Standards.

Force	± 1 percent
Displacement	∓ 2 percent
Temperature	∓ 5 °F

3.0 TEST OPERATIONS

3.1 Preliminary Preparations

		TEST OPERATIONS	INSPECTION	CUSTOMER APPROVAL
3.1.1	Install chassis reinforcements per assembly drawing 299025. (Certified welder required.)	4276 [illegible]		
3.1.2	Install 40 post yield strain gages as shown on special red-lined drawing 299025.	4276 [illegible]73		
3.1.3	Install the vehicle chassis in the test bay by welding per drawing 299025.	[illegible] 5-29-73		
3.1.4	Install the ROPS 299026 into the socket mounts 299027 and torque the eye bolts to 500±40 foot-pounds.	[illegible] 5-29-73		
3.1.5	Paint the assembly as required. Colors: chassis - olive drab; ROPS - yellow; tie-down fixtures - gray.	[illegible] 5-29-73		
3.1.6	Install the critical zone per SAE J-397A and drawing 299025.	[illegible] 5-29-73		
3.1.7	Prepare two 2' x 8' photo targets by carefully applying 1" black tape to a white background as shown in Figure 1.	[illegible] 5-29-73		

3.2 FOPS TEST

		TEST OPERATIONS	INSPECTION	CUSTOMER APPROVAL
3.2.1	Attach the 500-pound drop weight to a mobile crane using an electrically operated bomb release.	[illegible]		
3.2.2	Conduct sufficient practice drops on clear ground to ensure reliable release and good vertical attitude at the proposed impact point.	[illegible]		
3.2.3	Position the drop weight at the center of the ROPS section covered with wire mesh.	[illegible]		
3.2.4	Set up documentary movie cameras to record the drop sequence.	[illegible]		

TEST OPERATIONS	INSPECTION	CUSTOMER APPRVL

3.0 TEST OPERATIONS (Continued)

3.2.5 Install one photo target horizontally on the wall behind the critical zone to record the dynamic deflection of the steel mesh.

Revised 5-23-73

3.2.6 Install a 1" diameter x 6" long probe (approximate dimensions) extending downward under the drop point to be viewed by the high speed camera. Attach with wire, do not weld.

R vised 5-23-73

3.2.7 Position the 200 pps movie camera viewing the target grid at the same level as the critical zone top. See sketch, Figure 2.

3.2.8 Raise the weight 17 feet above the ROPS roof and conduct the ROPS test per SAE J-231.

3.2.9 Ensure the critical zone has not been violated. Take post test photographs per test engineer direction.

3.2.10 If the deformed wire mesh is too close to the critical zone to conduct the horizontal load test, restore it to the original minimum level.

3.3 Horizontal Load Test

3.3.1 Ensure load column center line is contacting the ROPS roof at the exact distance from the vertical supports as shown on drawing 299025 and is in a level attitude. The load distribution plate must span 20 inches minimum along the ROPS top and it must be free to rotate horizontally as load is applied.

3.3.2 Install precision scales for optical deflection measurements in accordance with drawing 299025 and position the surveyor's transits for viewing.

3.3.3 Install dial gages in accordance with drawing 299025.

TEST OPERATIONS	INSPECTION	CUSTOMER APPRVL

3.0 TEST OPERATIONS (Continued)

3.3.4 Calibrate all instrumentation and prepare for recording all data.

3.3.5 Take prefire photographs of the ROPS and test setup.

Revised 5-23-73

3.3.6 Install the two photo targets vertically on north and west walls behind the ROPS side surfaces to view the deformation during loading. Set up black and white still cameras on tripods and take one exposure at each inch of deflection. See sketch, Figure 2. Record and sketch exact camera placement.

3.3.7 Apply load to achieve incremental deflections of 0.5 inches and conduct the side loading in accordance with SAE J-394A.

3.3.8 Record the dial gages and optical scales at each inch of deflection.

3.3.9 At each deflection step, calculate total energy.

3.3.10 Continue loading until both the minimum load and minimum energy have been achieved.

NOTE

IF BOTH CONDITIONS OF LOAD AND ENERGY CANNOT BE SATISFIED, CONSULT THE TEST ENGINEER.

3.3.11 While at full load, ensure the critical zone has not been violated.

SAFETY NOTE

USE EXTREME CAUTION IN APPROACHING FULLY LOADED ASSEMBLY. A VIOLENT STRUCTURAL FAILURE COULD OCCUR AT ANY TIME.

			TEST OPERATIONS	INSPECTION	CUSTOMER APPROVAL
	3.0	TEST OPERATIONS (Continued)			
	3.3.12	Take documentary photographs per test engineer direction.	Hr 5-29-73		
	3.3.13	Remove the side load and record the post test measurements on all channels.	[illegible] 5-29-73		
	3.3.14	Take post test photographs per test engineer direction.	Hr 5-29-73		
	3.4	Vertical Load Test			
	3.4.1	Ensure load column is aligned to the center of the ROPS roof.	[illegible] 5-29-73		
	3.4.2	Ensure data acquisition for digital display and strain gage recording is ready for test.	5/29/73 1565		
Revised 5-23-73	3.4.3	Install one camera target horizontally behind the ROPS and set up black and white camera on a tripod to record deflection at each vertical load increment. Record and sketch exact camera placement.	[illegible] 5-29-73		
Revised 5-23-73	3.4.4	Apply load increments of 10K, 16K, 21K, 22K, 23K, and full load of 23.5K in accordance with SAE J-394A, paragraph 5.2. Record all specified data channels and optical deflection measurements at each load increment.	5/29/73 1565		
	3.4.5	While at full load, verify that the critical zone has not been violated.	[illegible] 5-29-73		
	3.4.6	Take documentary photographs per test engineer direction.	Hr 5-29-73		
	3.5	Horizontal Failure Test			
	3.5.1	Remove vertical loading system and re-install the horizontal load column.	[illegible] 5-29-73		
Revised 5-23-73	3.5.2	Resume horizontal loading at .5-inch increments until structural failure occurs or as directed by the test engineer.	[illegible] 5-29-73		
	3.5.3	Take post test photographs per test engineer direction.	Hr 5-29-73		

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM MERDC 6K FORKLIFT TEST DATE 5/24/73

	DEFLECTION - INCHES									
———	PRE ZERO	1	2	3	4	5	6	7	8	POST ZERO
1-S	1.00	2.25	3.53	4.75	5.90	7.18	8.31	9.47	10.53	4.39
2-S	1.00	1.31	1.68	1.96	2.18	2.~~00~~53	2.84	9.47	10.53	4.78
3-S	6.00	.520	4.40	3.70	2.90	2.00	1.20	2.00	—	3.30
1-D	.400	.382	.371	.359	.344	.323	.310	.301	.294	.363
2-D	.200	.274	.252	.233	.210	.192	.158	.138	.119	.241
3-D	.100	.182	.165	.150	.040	.028	.018	.017	.018	.064

Prepared by: 4276 5/24/73 Approved by: H C Pearson

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K Forklift TEST DATE 29 May 1973

HORIZONTAL LOAD TEST PER SAE J-394A

REQUIRED ENERGY, U, POUND-INCHES, 122,204

REQUIRED MINIMUM HORIZONTAL LOAD 15,031 POUNDS

TEST STEP	Δ NOMINAL	Δ ACTUAL	HORIZONTAL LOAD APPLIED	CALCULATED ENERGY, U
1	0.5	0.524	2,490	652
2	1.0	1.00	5,250	2,508
3	1.5	1.50	7,770	5,725
4	2.0	2.00	10,390	10,440
5	2.5	2.51	12,580	16,060
6	3.0	3.02	14,650	22,993
7	3.5	3.48	16,290	30,177
8	4.0	3.97	17,850	38,614
9	4.5	4.51	19,680	48,733
10	5.0	4.99	20,810	58,436
11	5.5	5.51	21,650	69,460
12	6.0	5.99	22,180	79,909
13	6.5	6.49	22,650	91,157
14	7.0	7.01	22,950	102,995
15	7.5	7.50	23,080	114,257
16	8.0	8.00	23,150	125,797
		3.22	-0-	
17	8.5	8.55	23,150	138,569
18	9.0	9.02	23,580	149,535
19	9.5	9.55	23,710	162,048
20	10.0	10.02	23,780	173,311
21	10.5	10.51	23,850	184,845
22	11.0	11.04	23,950	197,613
23	11.5	11.50	23,950	208,734
24	12.0	12.50	24,000	232,674

Prepared by: B.J. Miller Approved by: H C Baum

Figure 1 - Test Set Up - Horizontal Load

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K FORKLIFT TEST DATE 29 May 1973

Prepared by: [signature] Approved by: [signature]

Figure 2

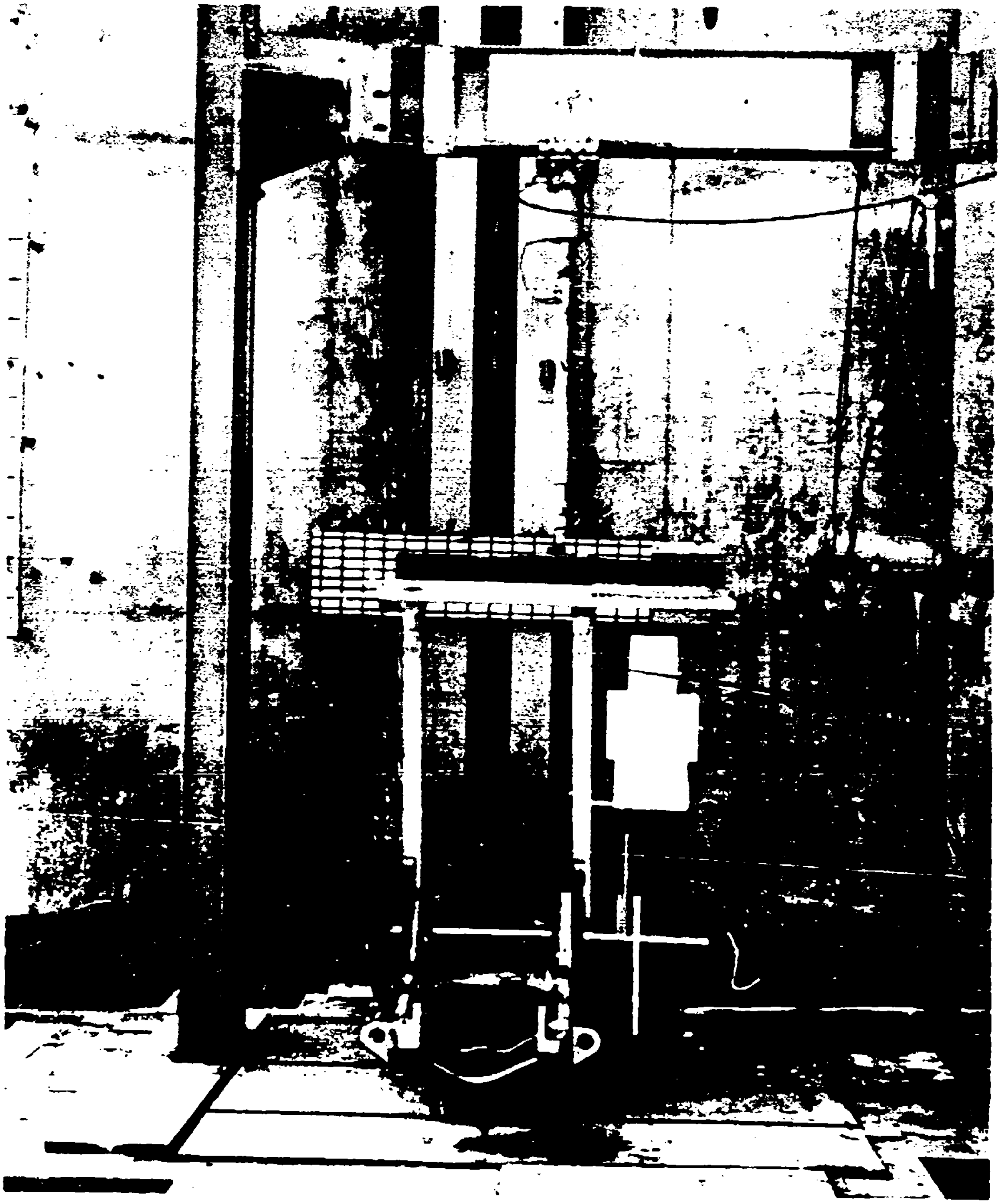


Figure 3 - Vertical Load

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K Forklift Vertical Loading TEST DATE 29 May 1973

LOAD-LBS	DEFL/IN
0	.0
10274	1.40
16179	2.11
21196	3.04
22150	3.28
22985	3.74
23681	3.74

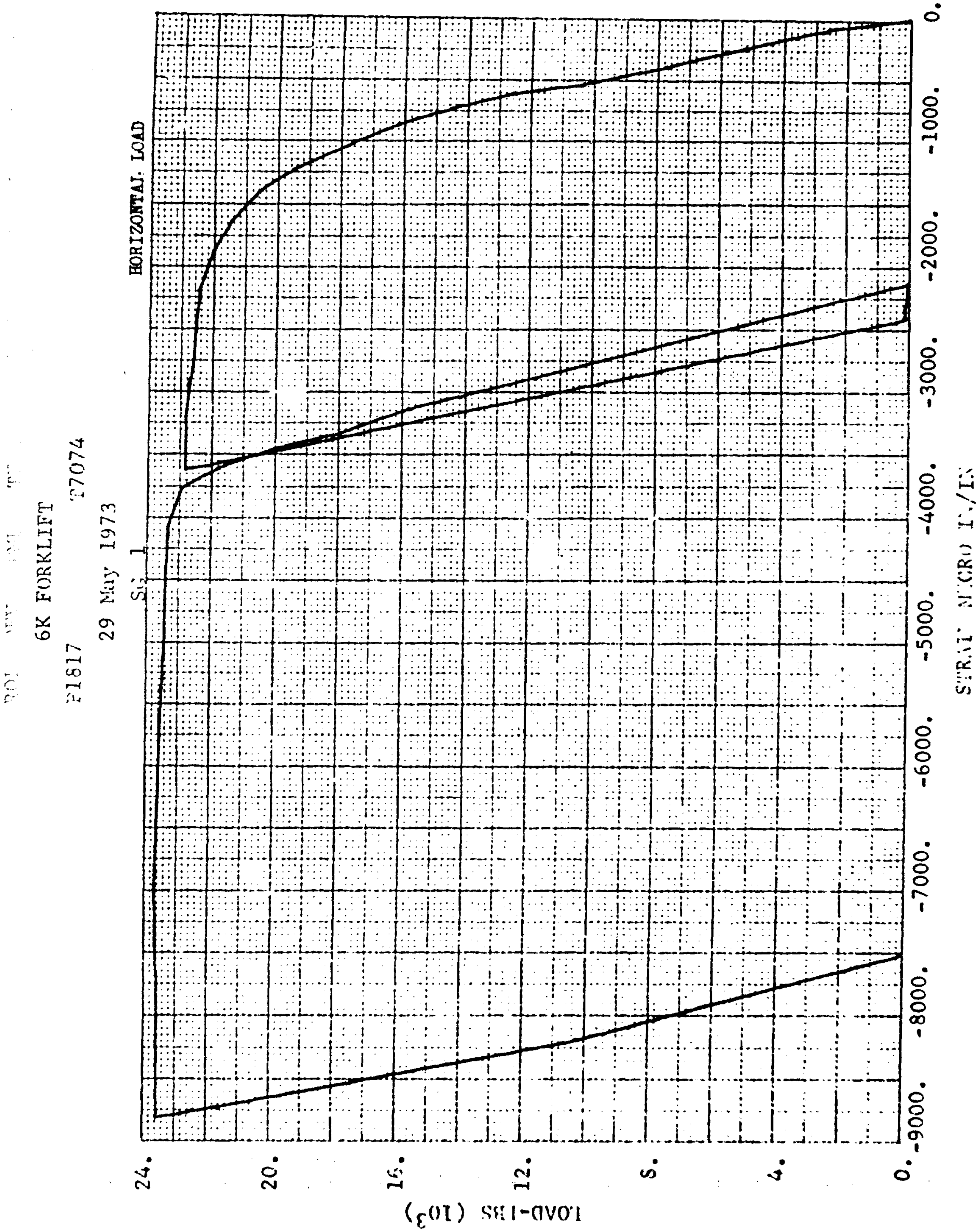
Prepared by: [illegible signature] Approved by: [illegible signature]

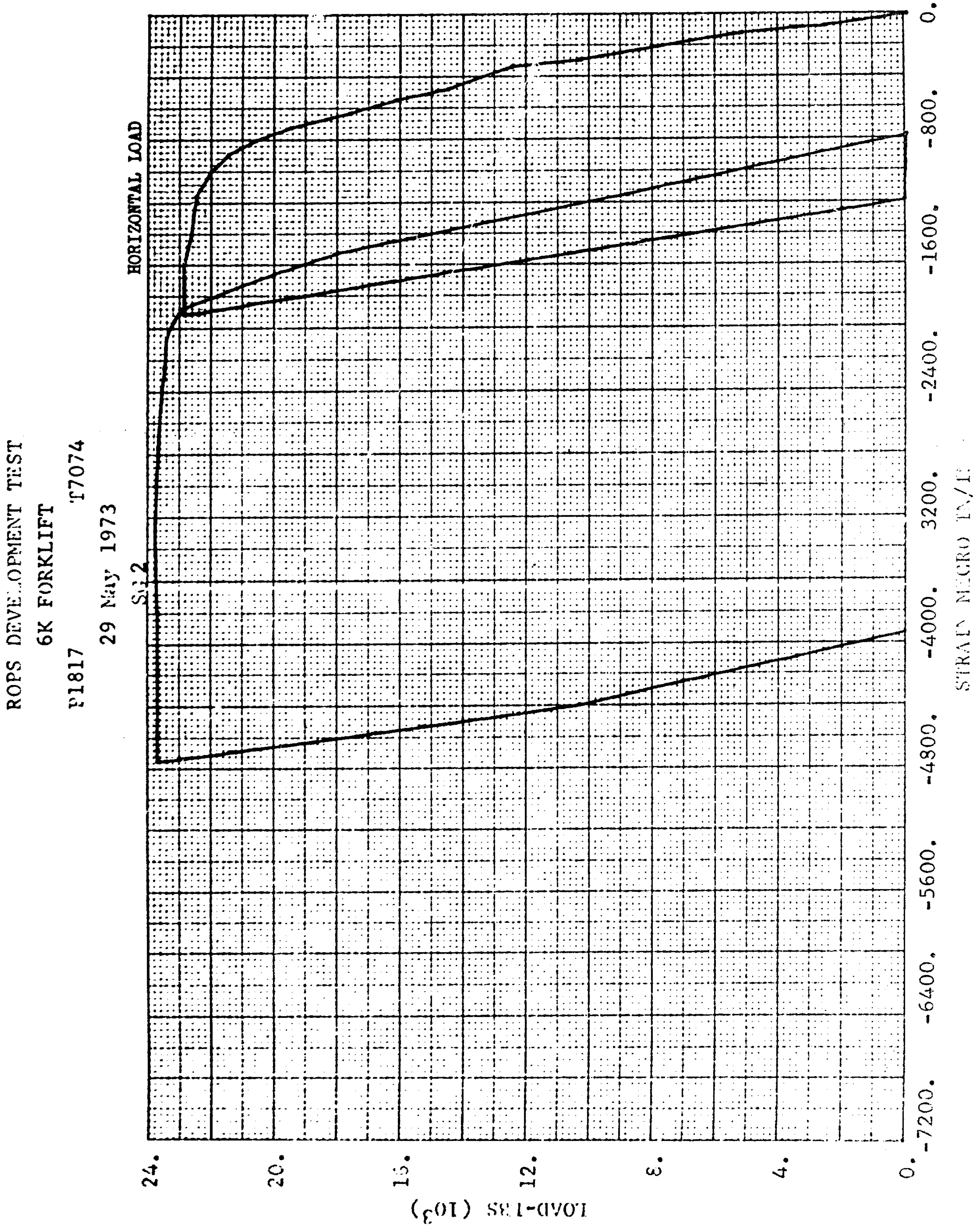
TR-684-059

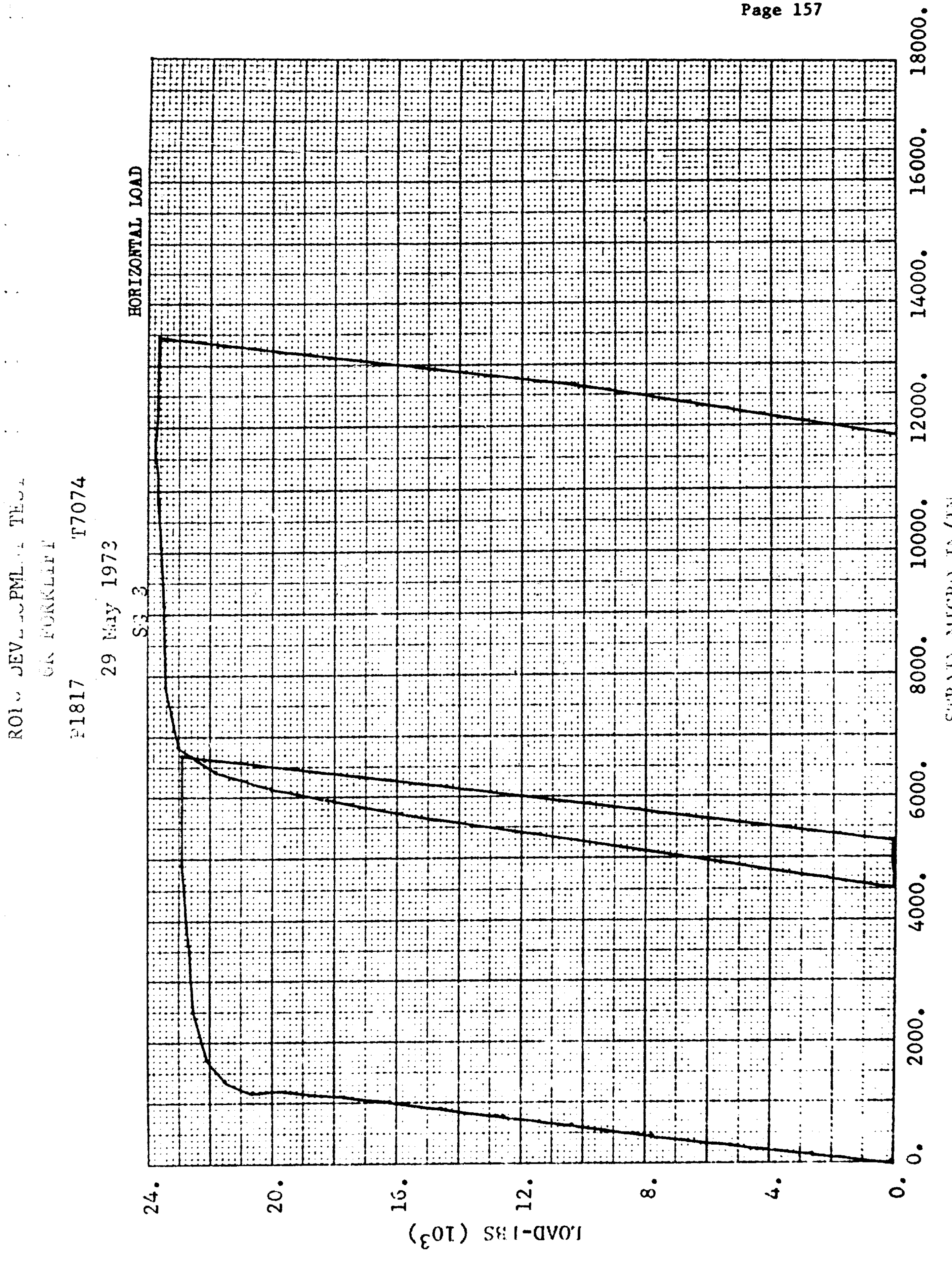
ADDENDUM I

PLOTS OF STRAIN VERSUS LOAD

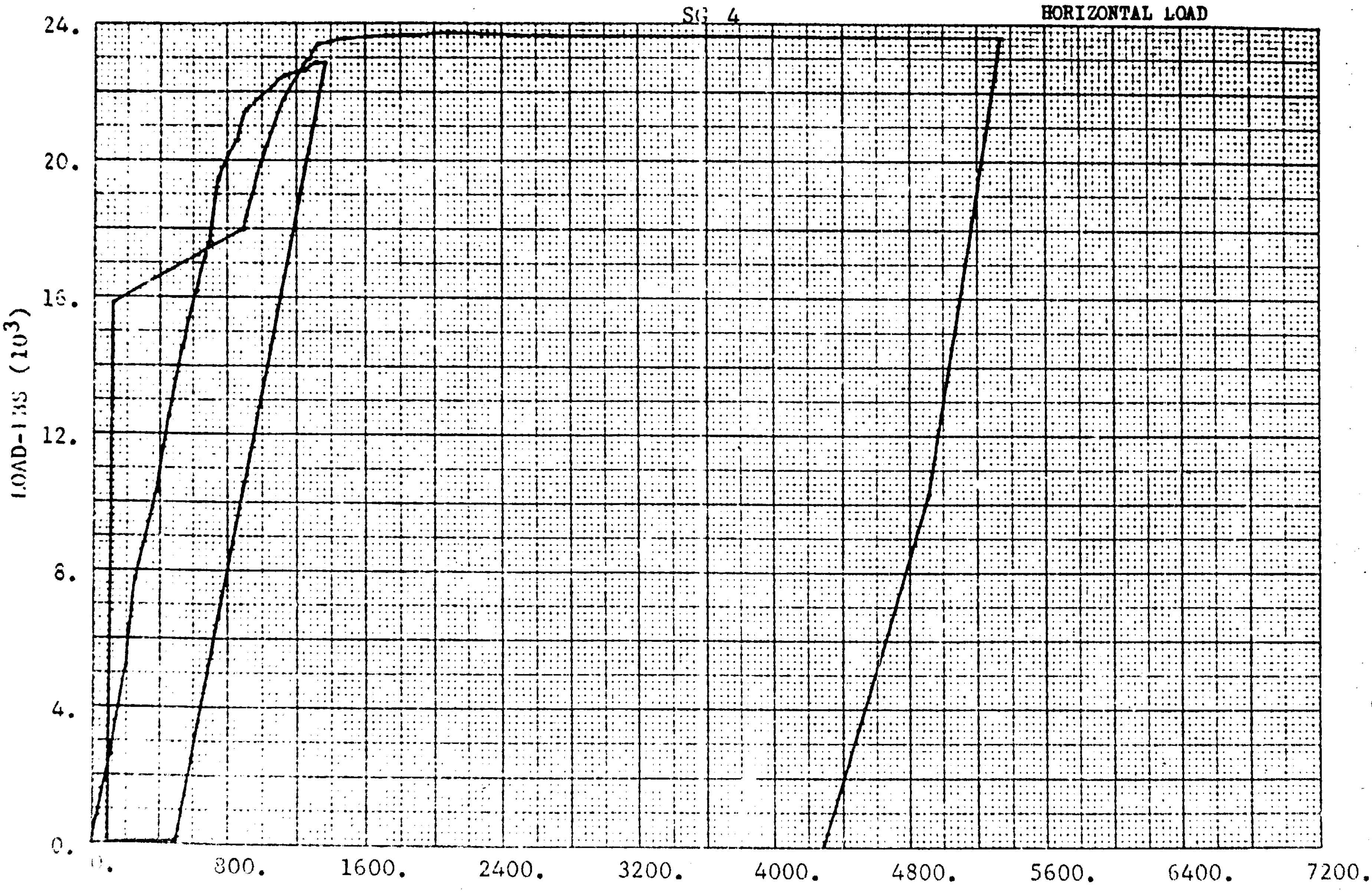
DURING HORIZONTAL LOADING

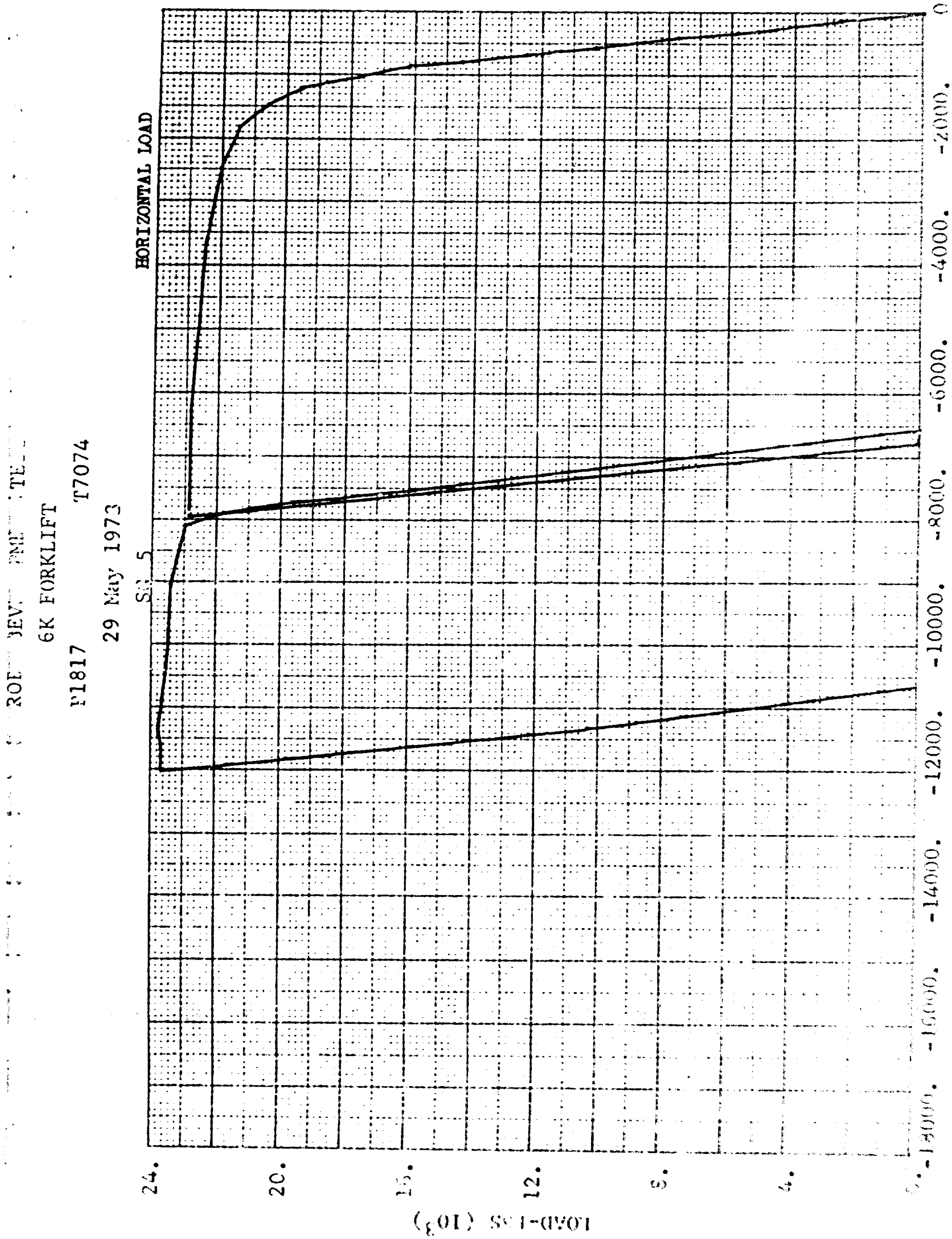

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
0.
-1000.
-2000.
-3000.
-4000.
-5000.
-6000.
-7000.
-8000.
-9000.
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
HORIZONTAL LOAD
0.
-800.
-1600.
-2400.
3200.
-4000.
-4800.
-5600.
-6400.
-7200.
24.
20.
12.
8.
4.
0.
LOAD-LBS (10³)

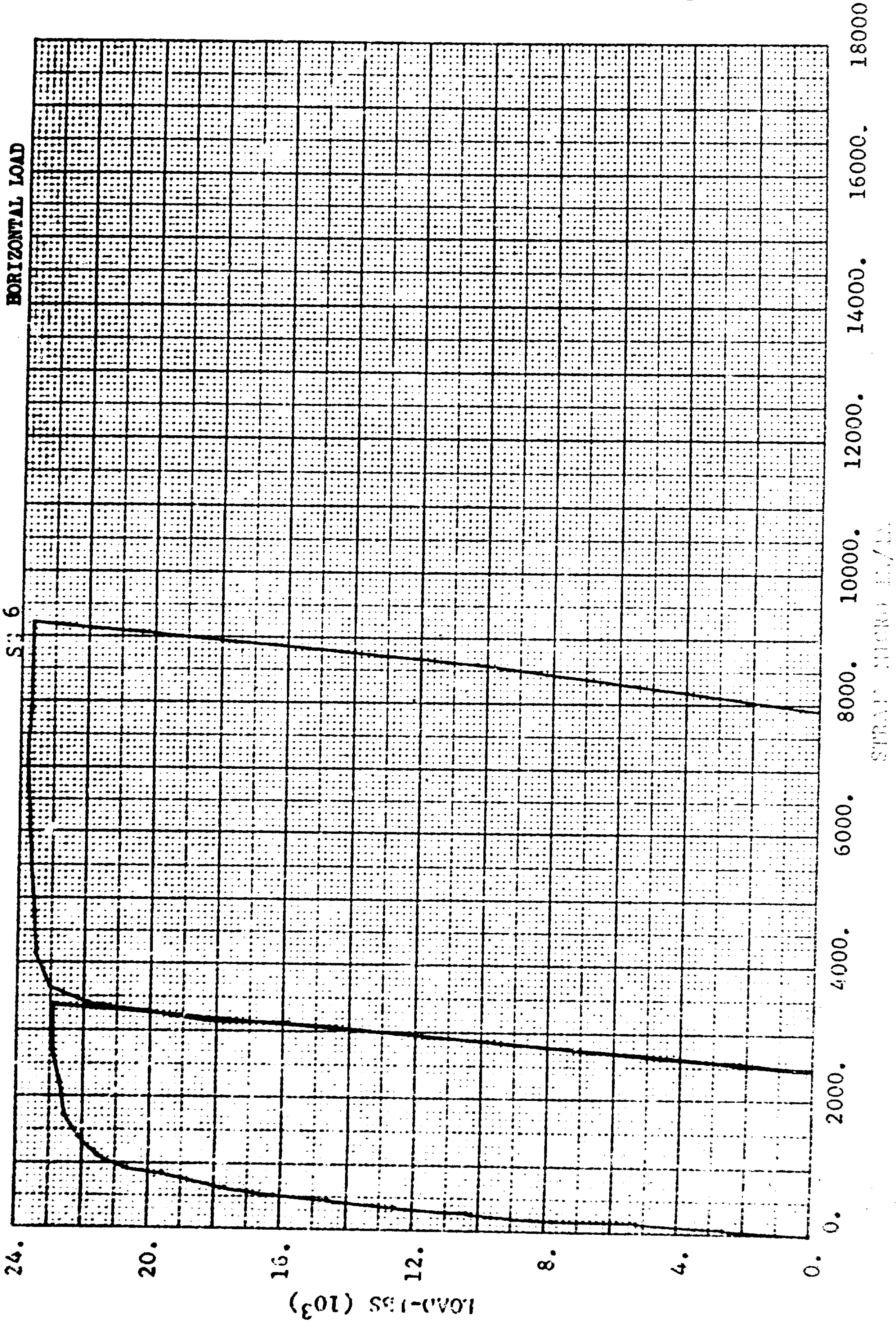

P1817 T7074
29 May 1973
HORIZONTAL LOAD
0. 2000. 4000. 6000. 8000. 10000. 12000. 14000. 16000. 18000.
0. 4. 8. 12. 16. 20. 24.
LOAD-LBS (10³)

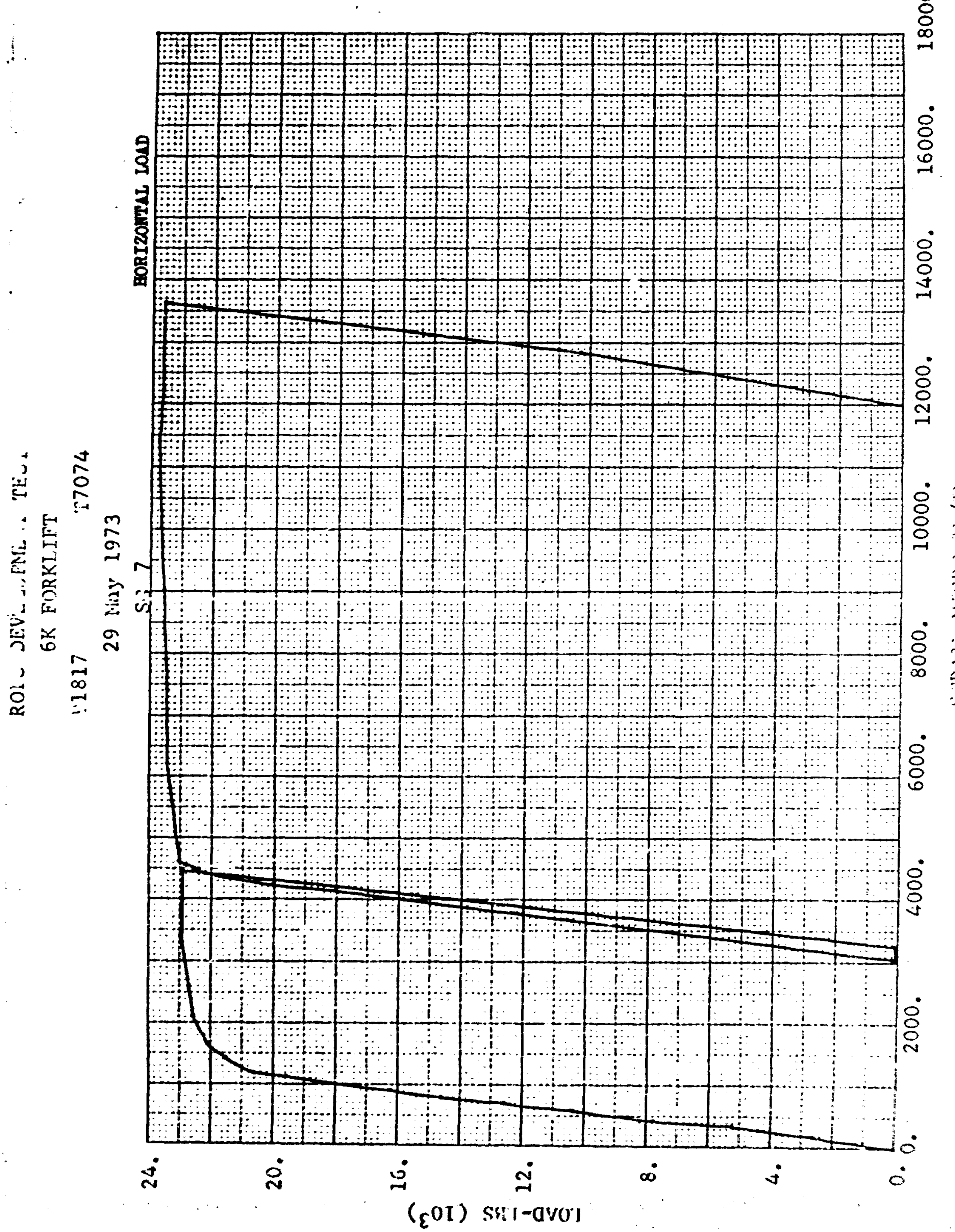
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



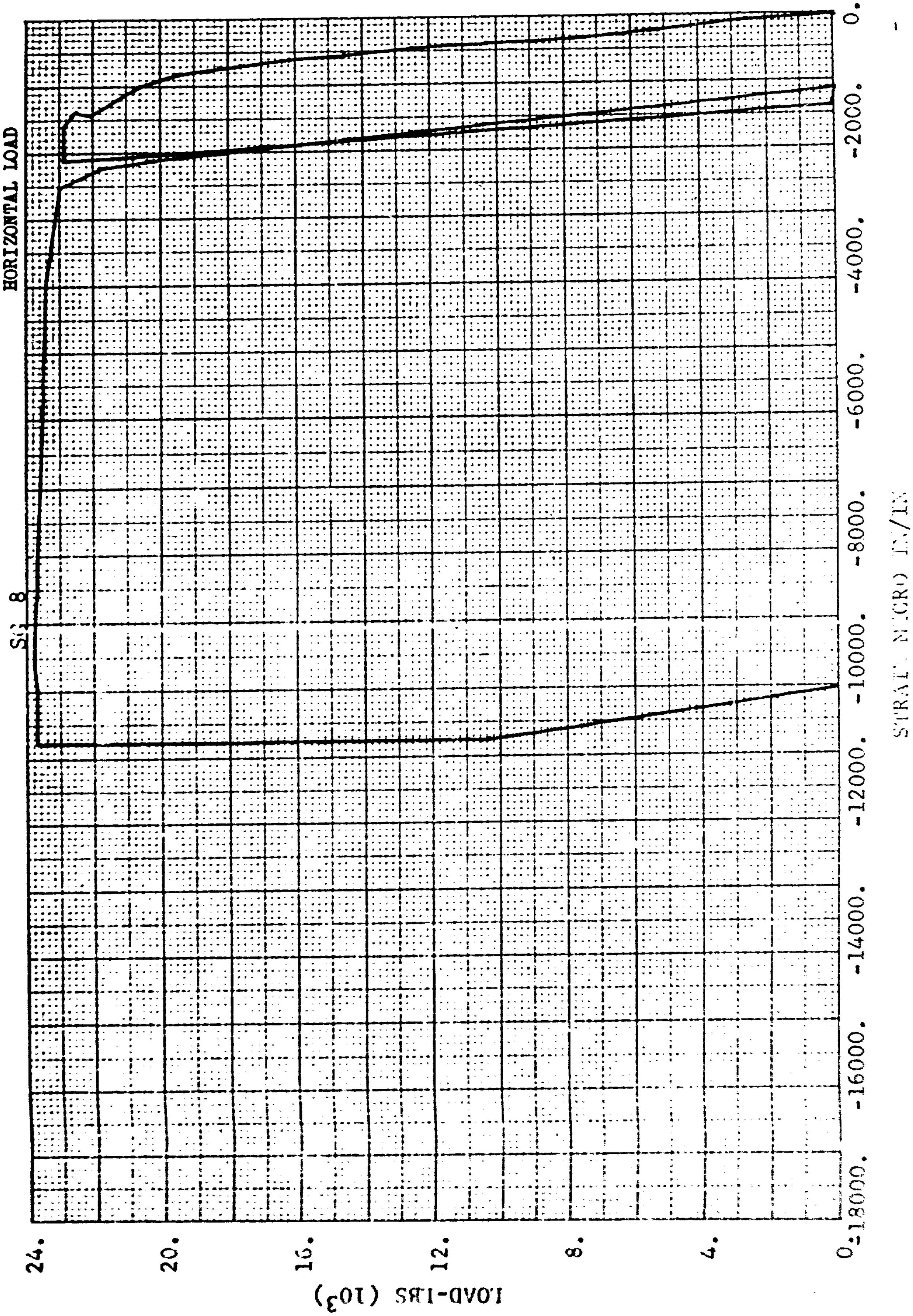

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
0.
-2000.
-4000.
-6000.
-8000.
-10000.
-12000.
-14000.
24.
20.
16.
12.
8.
4.
LOAD-LBS (10^3)

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
S: 6




6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
0.
2000.
4000.
6000.
8000.
10000.
12000.
14000.
16000.
18000.
0.
4.
8.
12.
16.
20.
24.

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



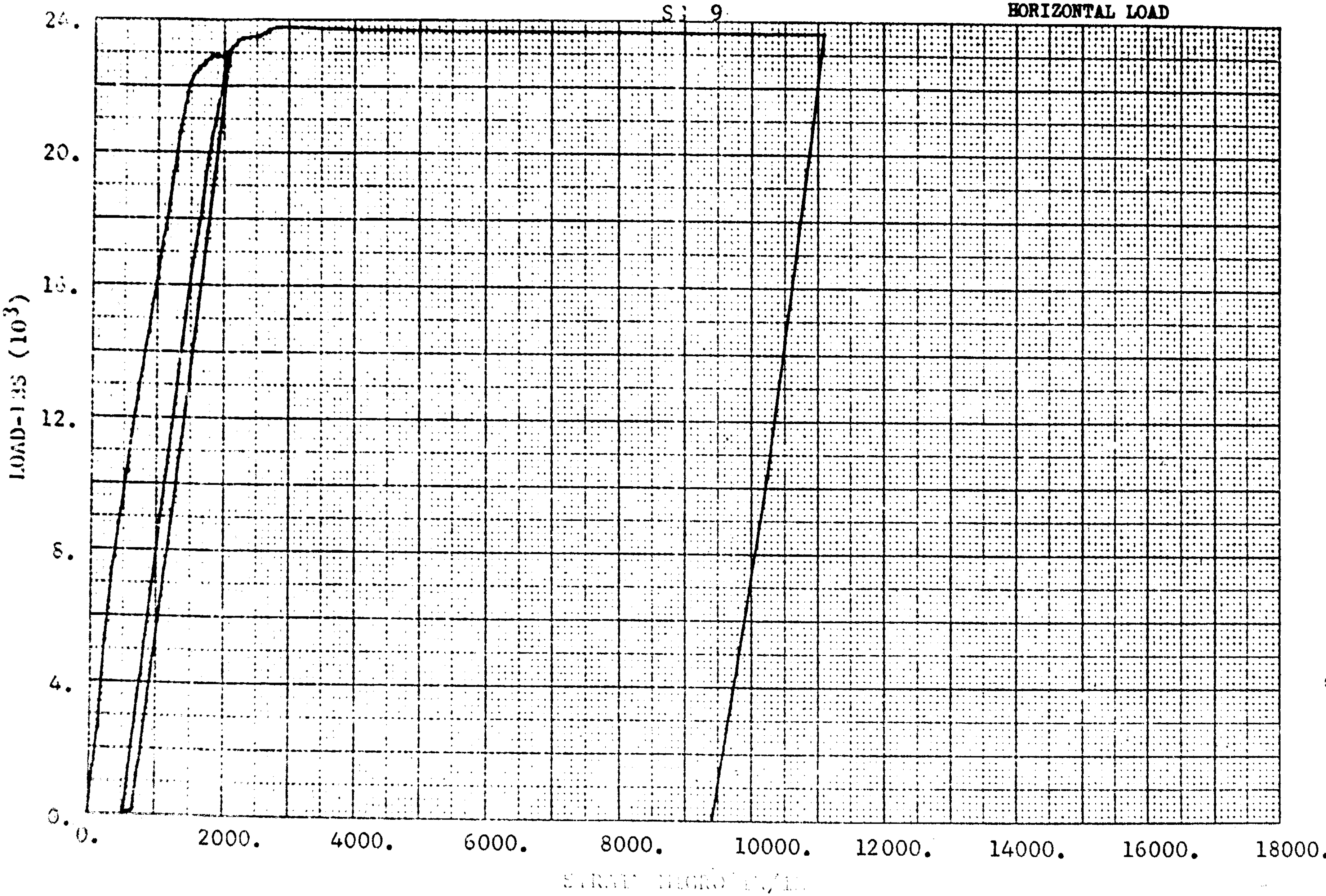
RO[illegible] DEVE[illegible]PME[illegible] TE[illegible]

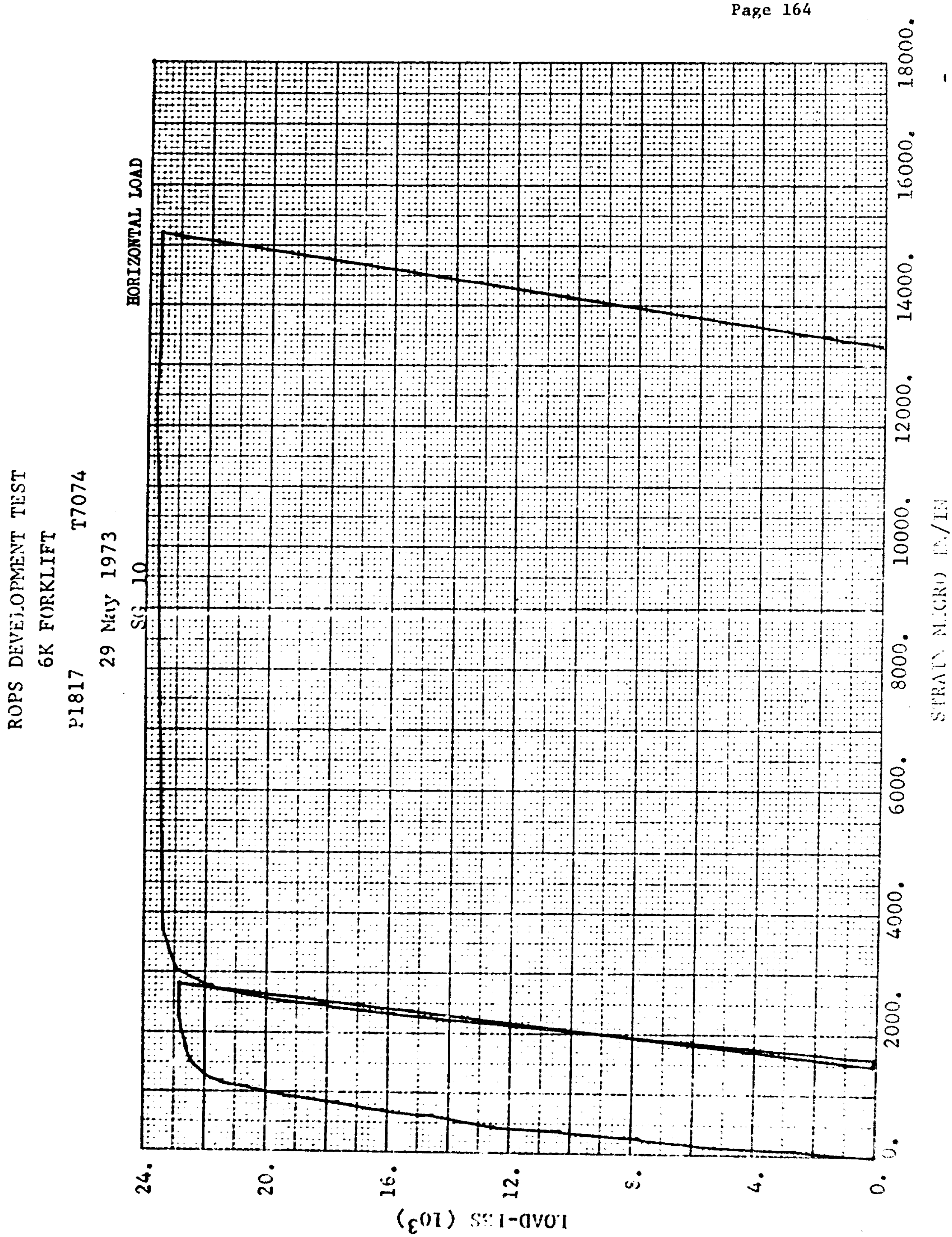
6K FORKLIFT

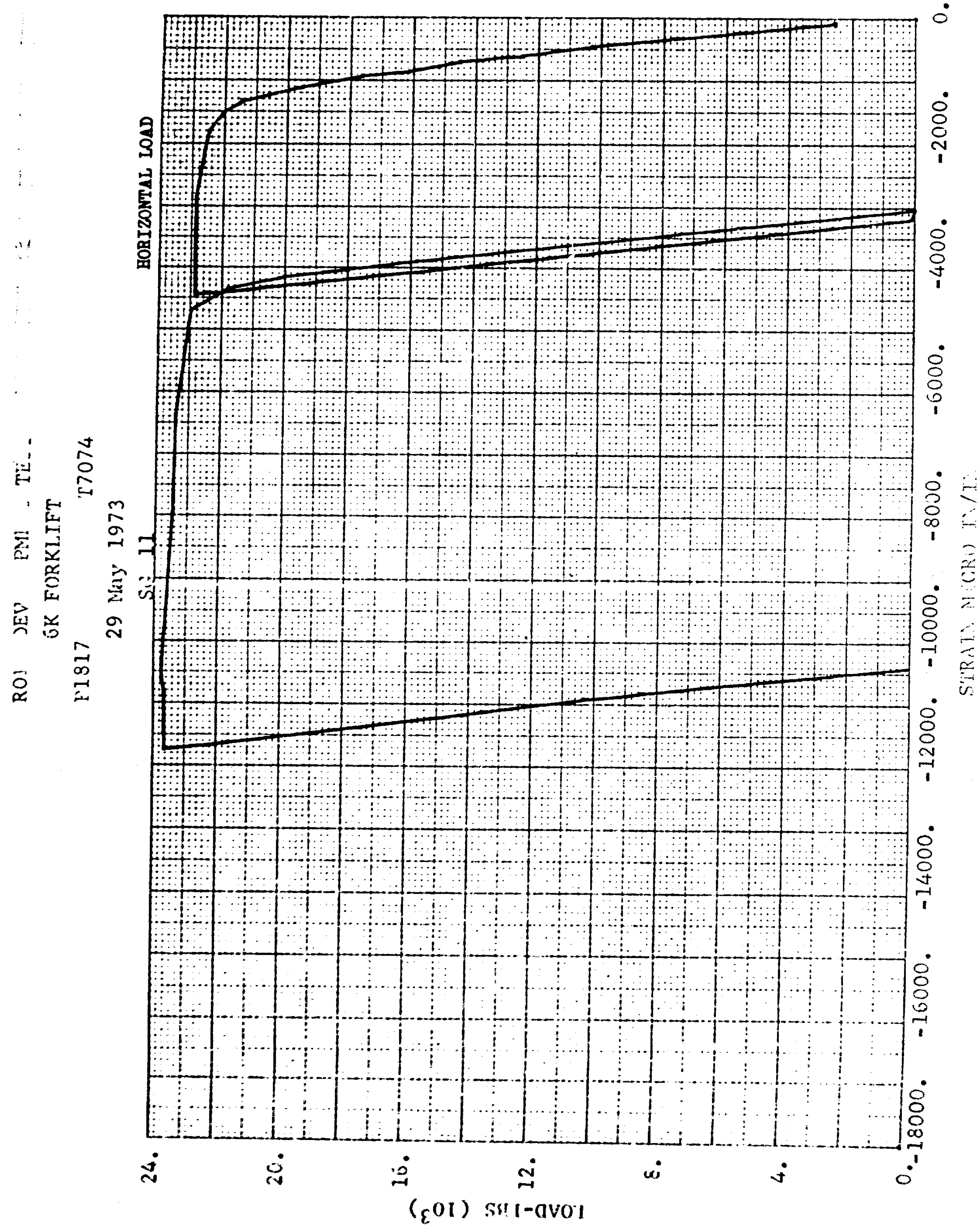
[illegible]1817 T7074

29 May 1973

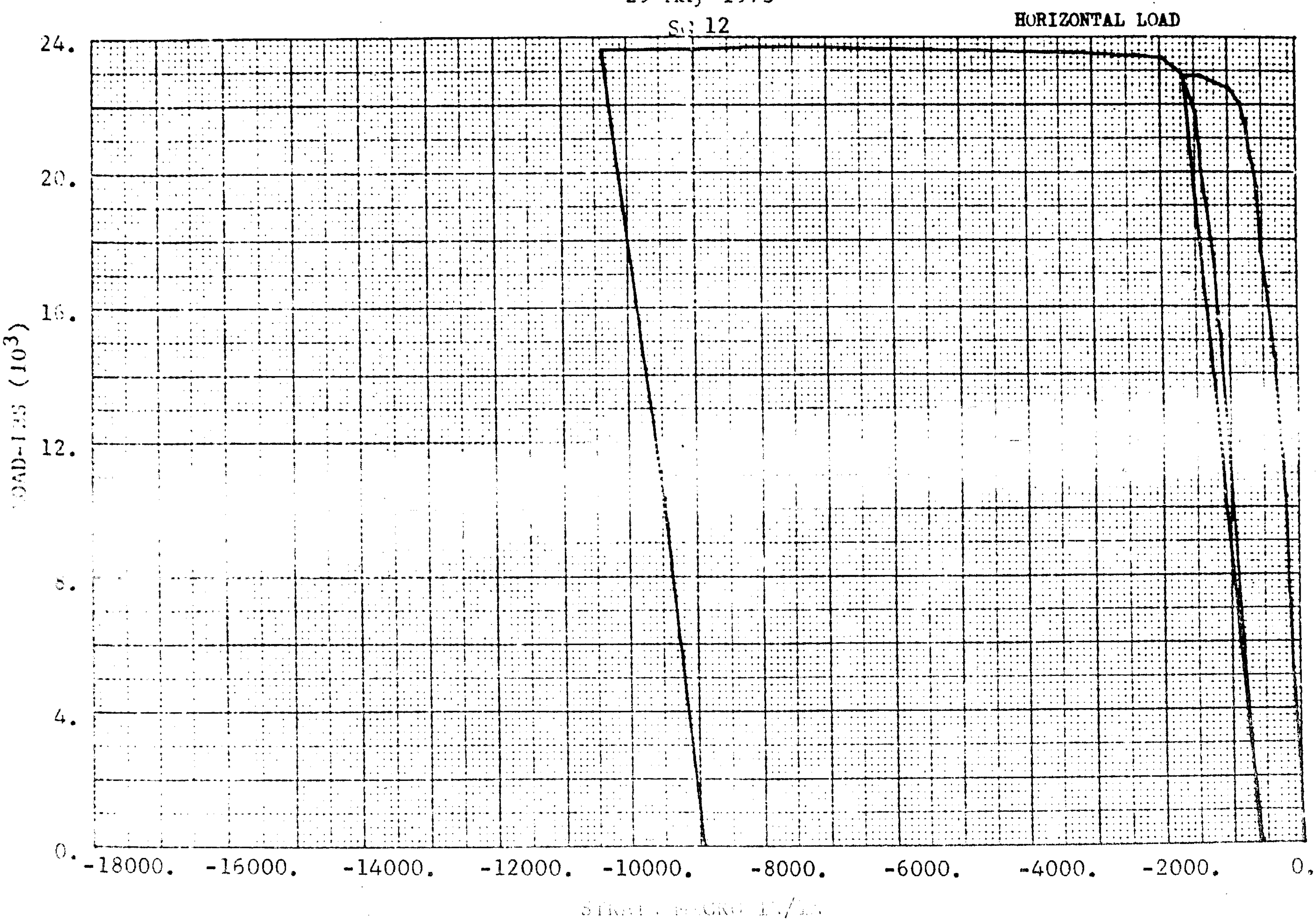
S[illegible] 9

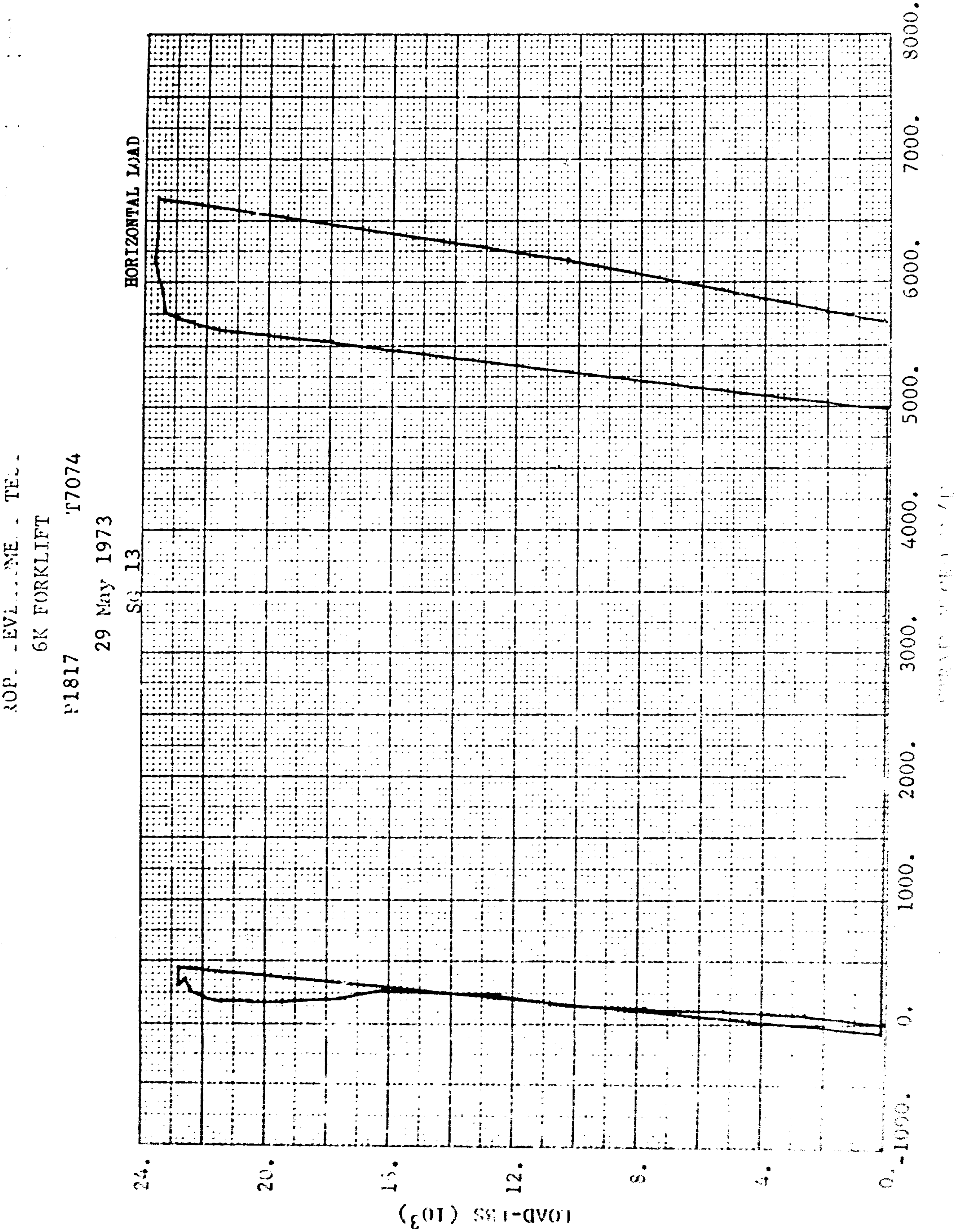



ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 10
HORIZONTAL LOAD
0.
2000.
4000.
6000.
8000.
10000.
12000.
14000.
16000.
18000.
0.
4.
8.
12.
16.
20.
24.

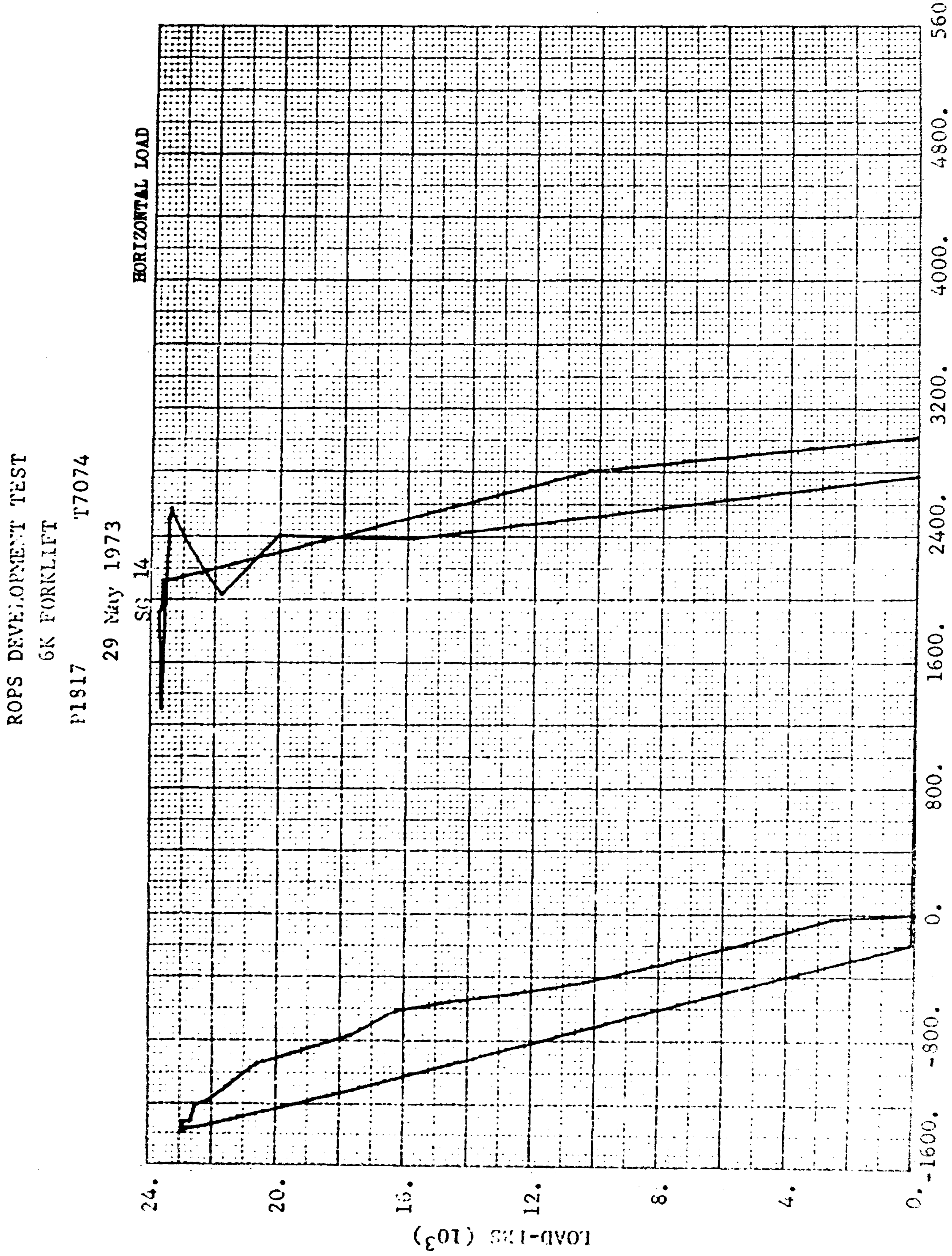

6K FORKLIFT
P1817
T7074
29 May 1973
HORIZONTAL LOAD
0.
-2000.
-4000.
-6000.
-8000.
-10000.
-12000.
-14000.
-16000.
-18000.
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10³)

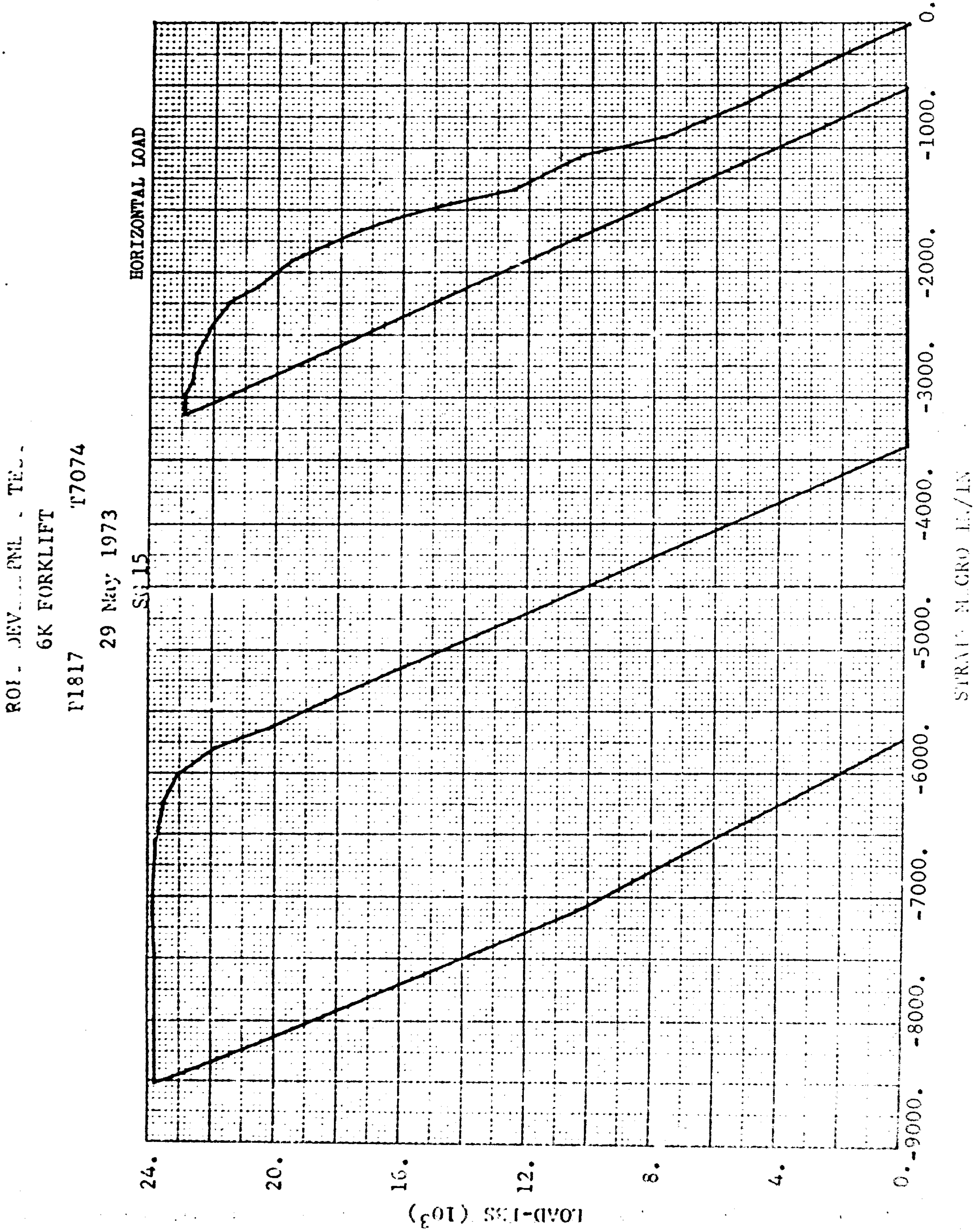
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 12



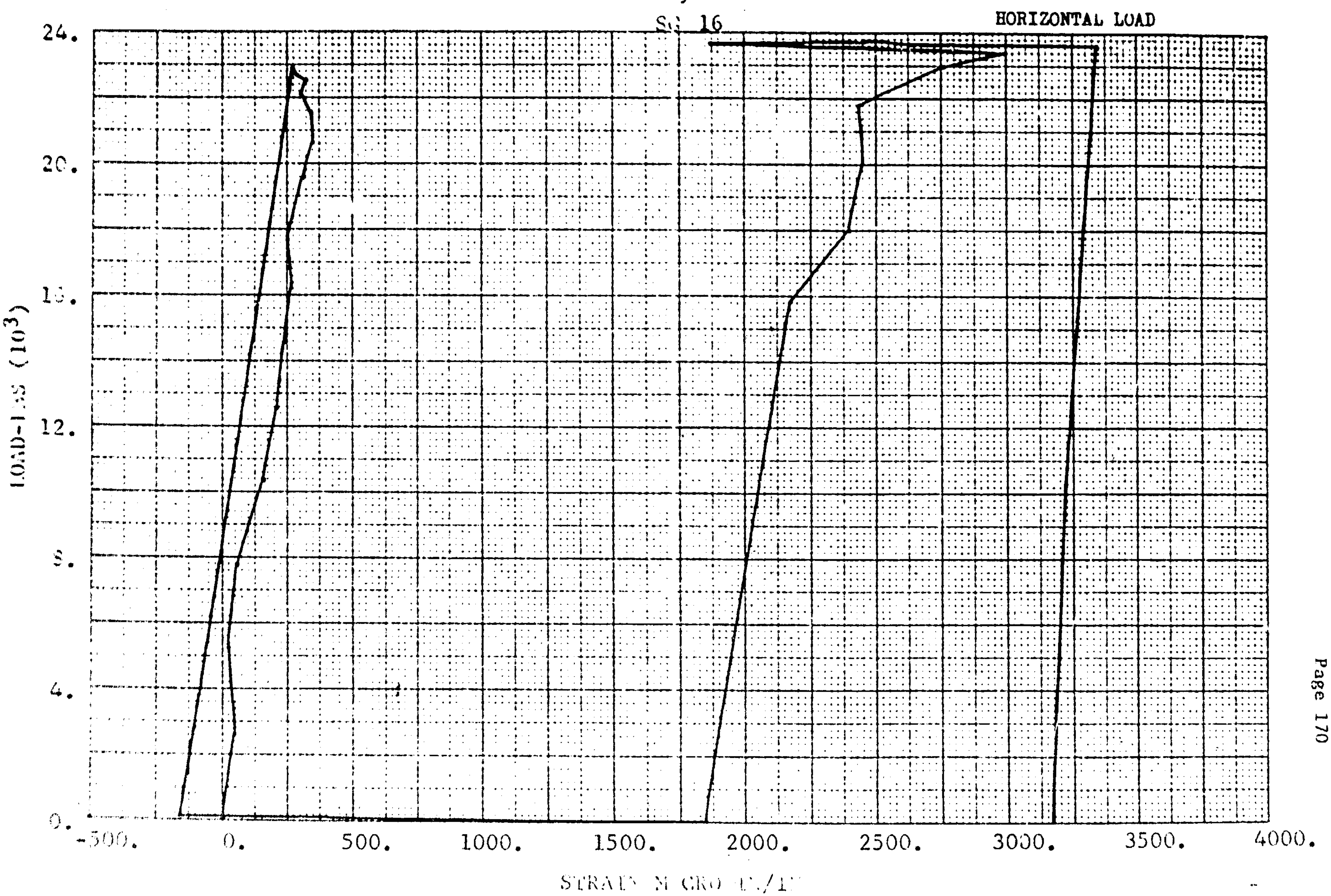

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
24.
20.
12.
8.
4.
0.
-1000.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.

14


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 14
HORIZONTAL LOAD
5600.
4800.
4000.
3200.
2400.
1600.
800.
0.
-800.
-1600.
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10³)


ROI . DEV. . . PNL . TE. .
6K FORKLIFT
F1817 T7074
29 May 1973
S1 15
HORIZONTAL LOAD
0.
-1000.
-2000.
-3000.
-4000.
-5000.
-6000.
-7000.
-8000.
-9000.
STRAIN MICRO IN/IN
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)

ROPS DEVELOPMENT TEST
6K FORKLIFT
F1817 T7074
29 May 1973
SG 16



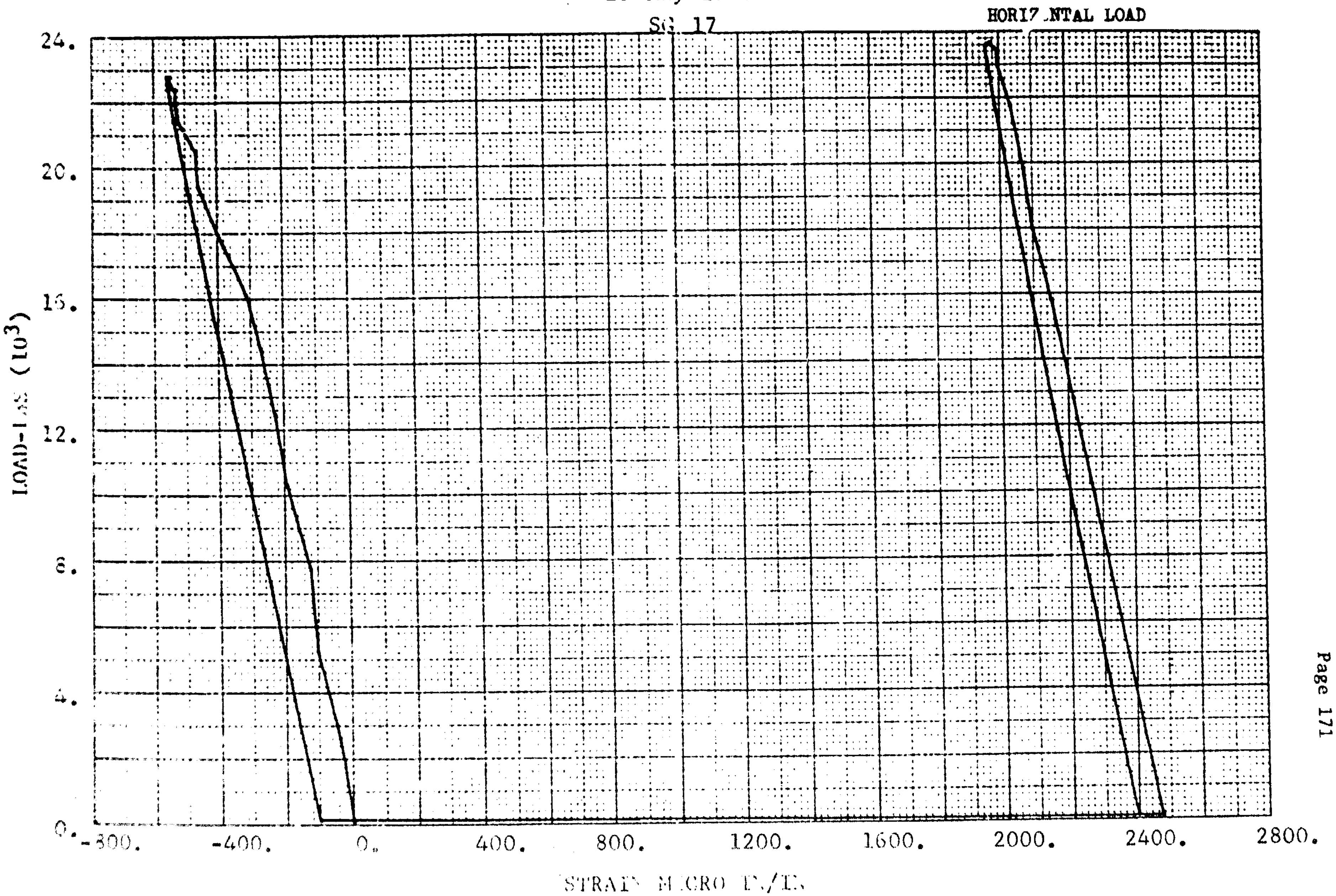
ROP_ _EVL_ _ME _ TE_

6K FORKLIFT

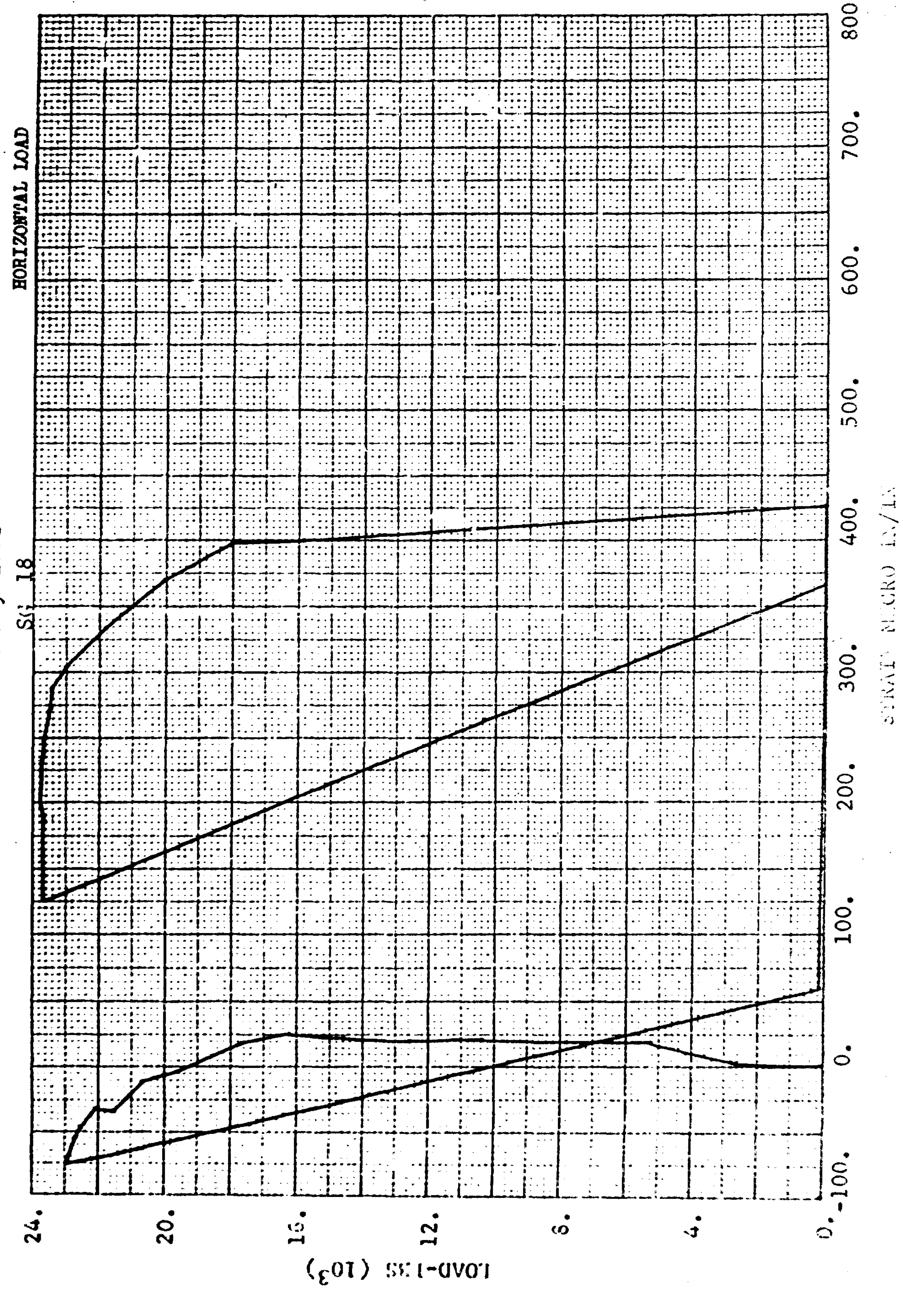
P1817 T7074

29 May 1973

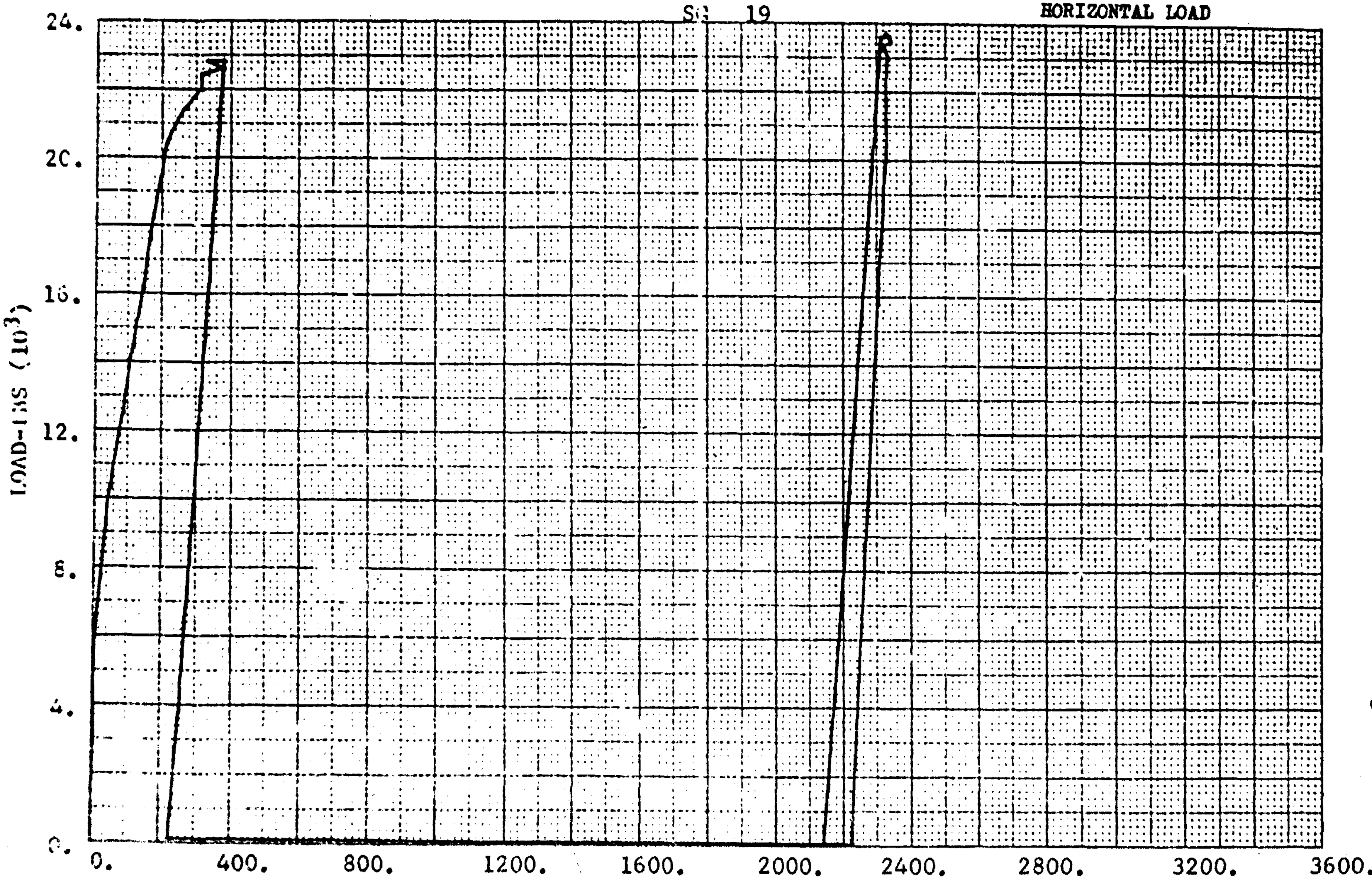
SG 17

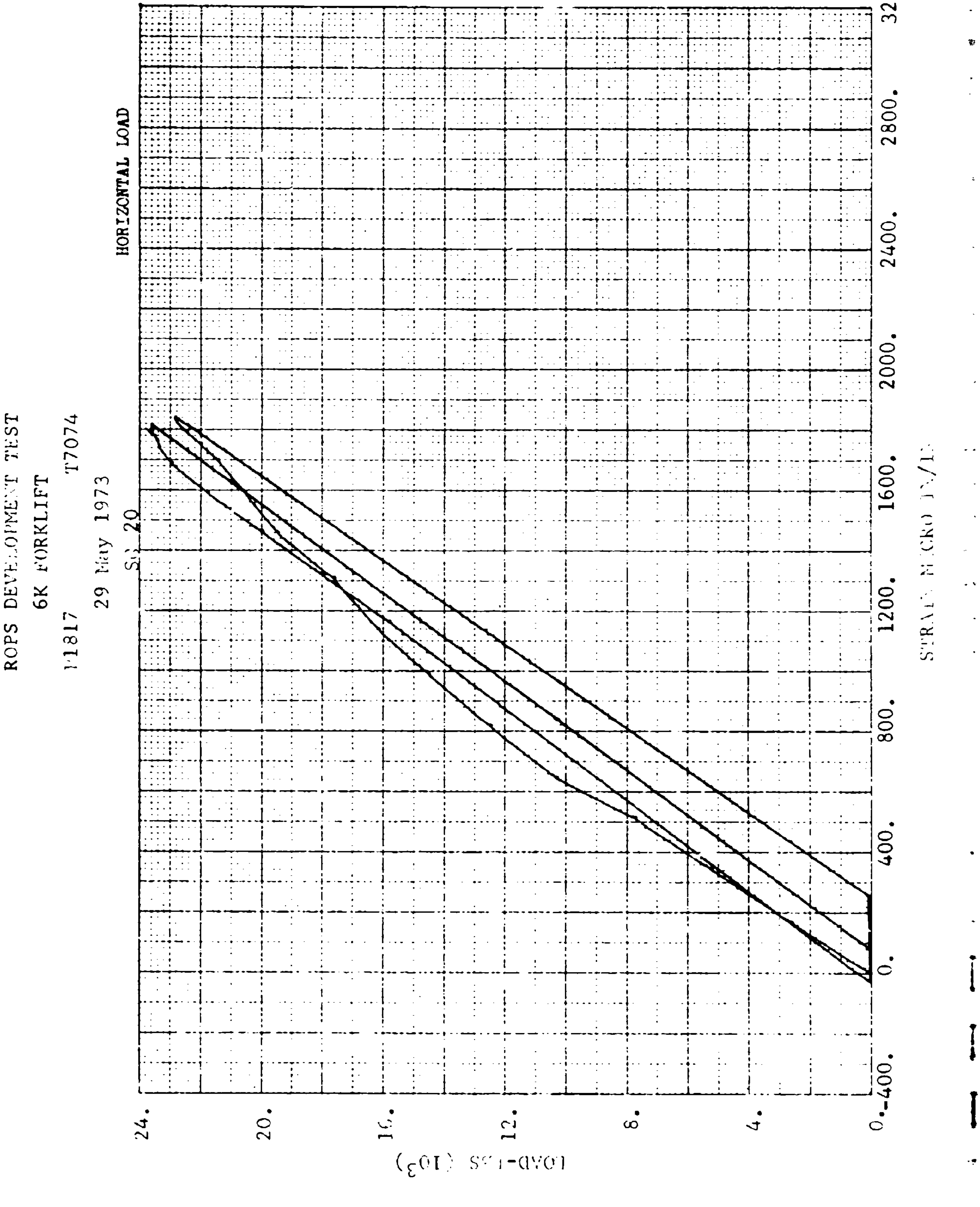


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



RO.. DEV...OPM... TE...
6K FORKLIFT
P1817 T7074
29 May 1973
S. 19




ROPS DEVELOPMENT TEST
6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
LOAD-LBS (10^3)
STRAIN MICRO IN/IN
24.
20.
12.
8.
4.
0.
-400.
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.

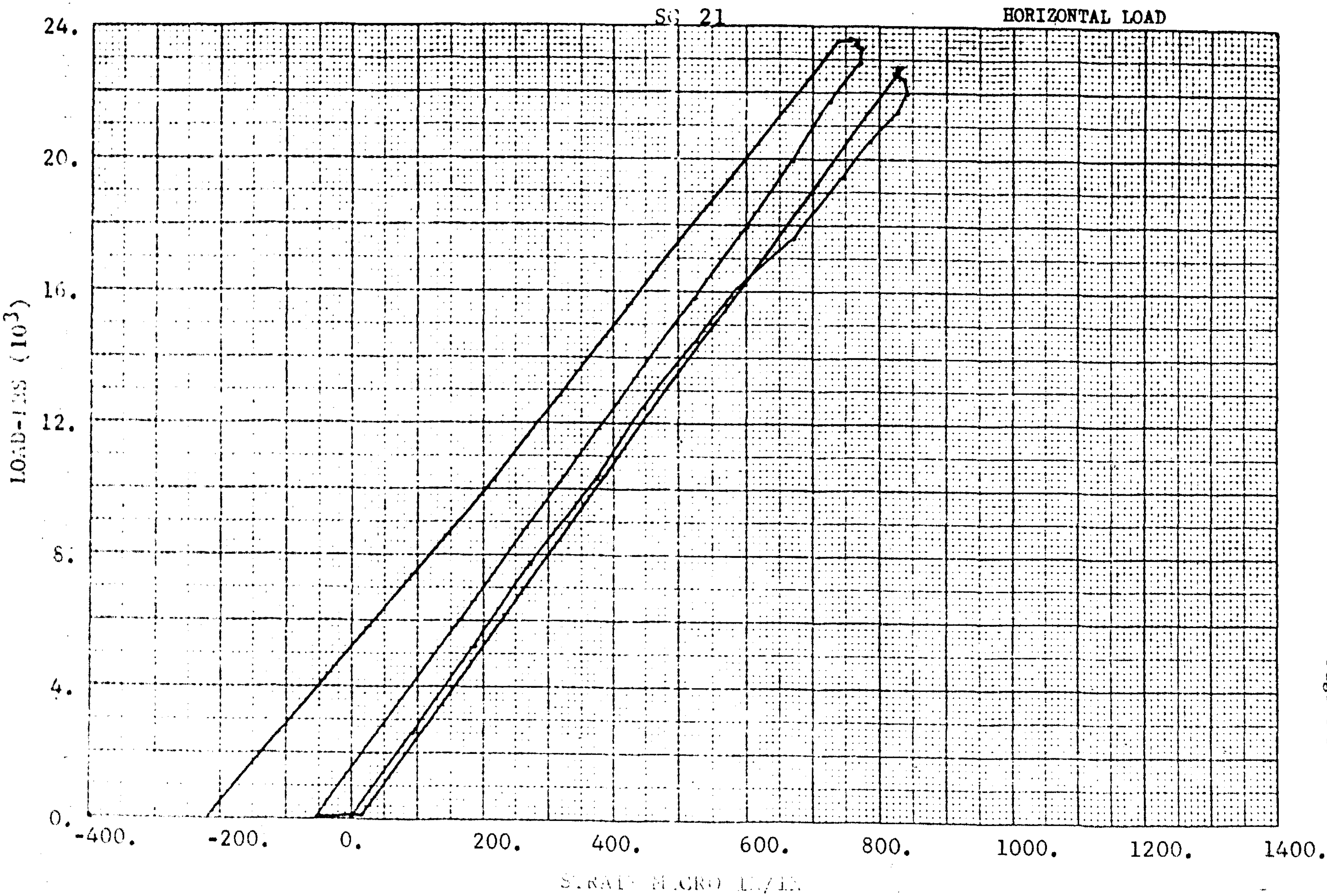
ROF[illegible] DEV[illegible]OPME[illegible] TE[illegible]

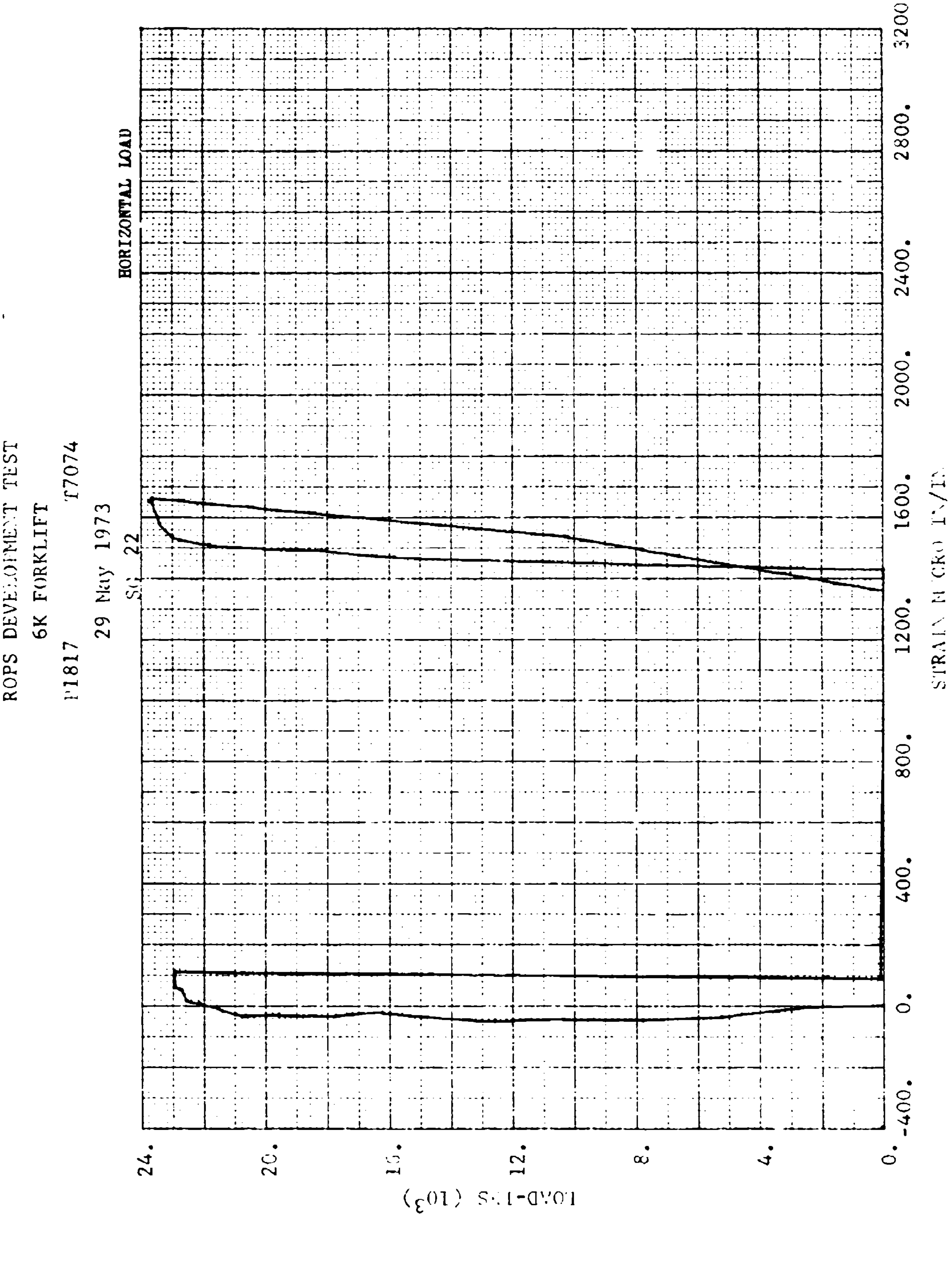
6K FORKLIFT

P1817 T7074

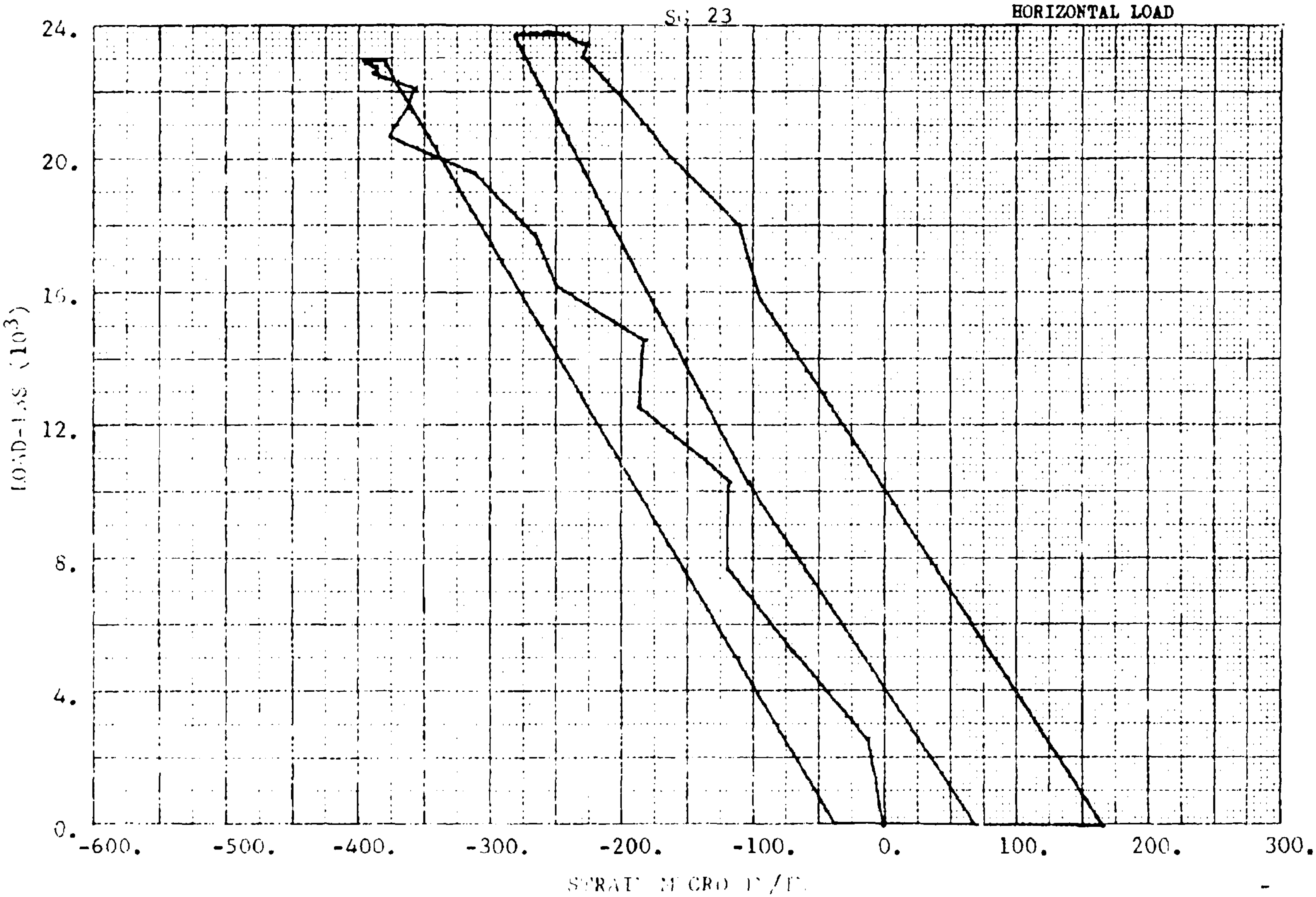
29 May 1973

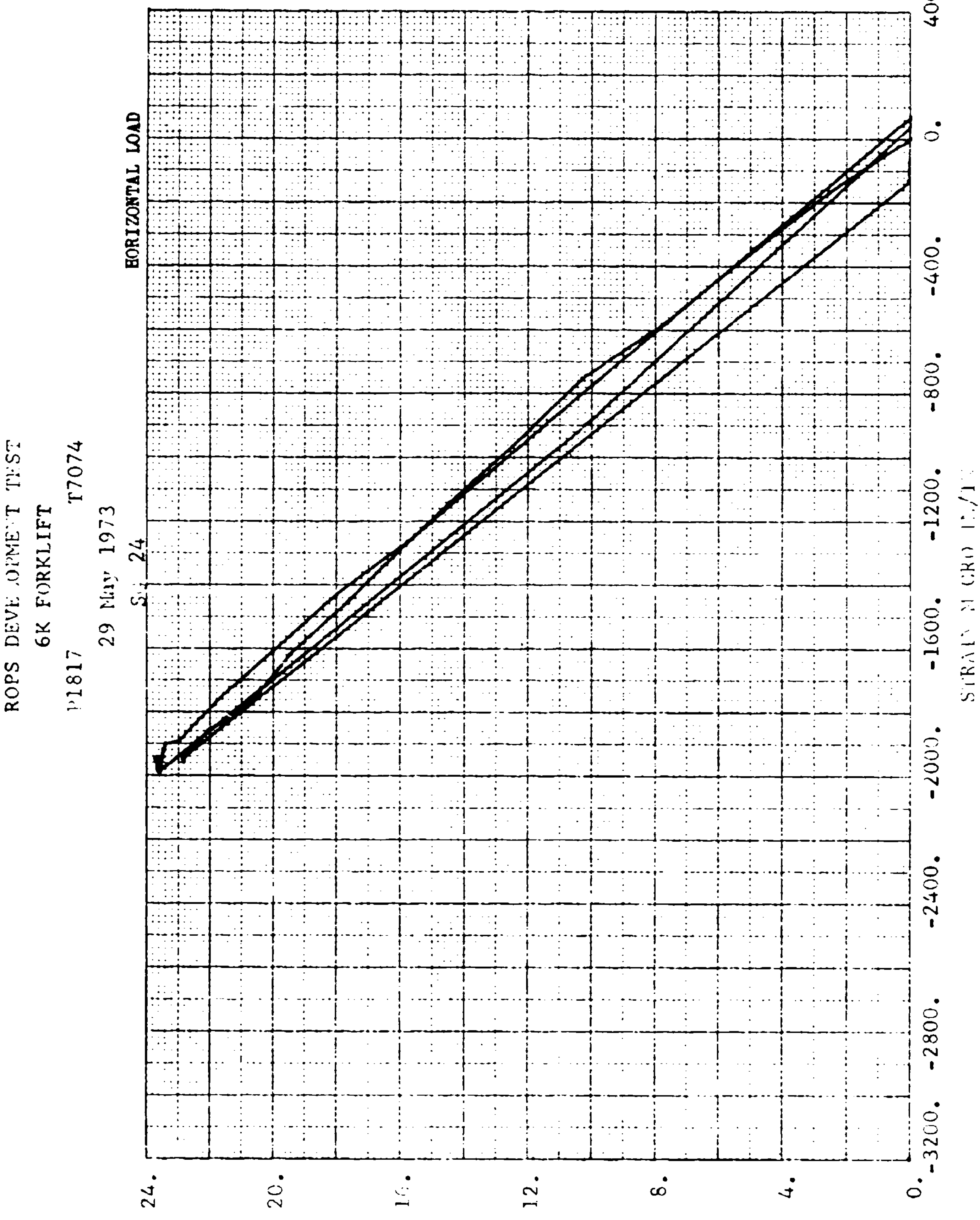
SG 21

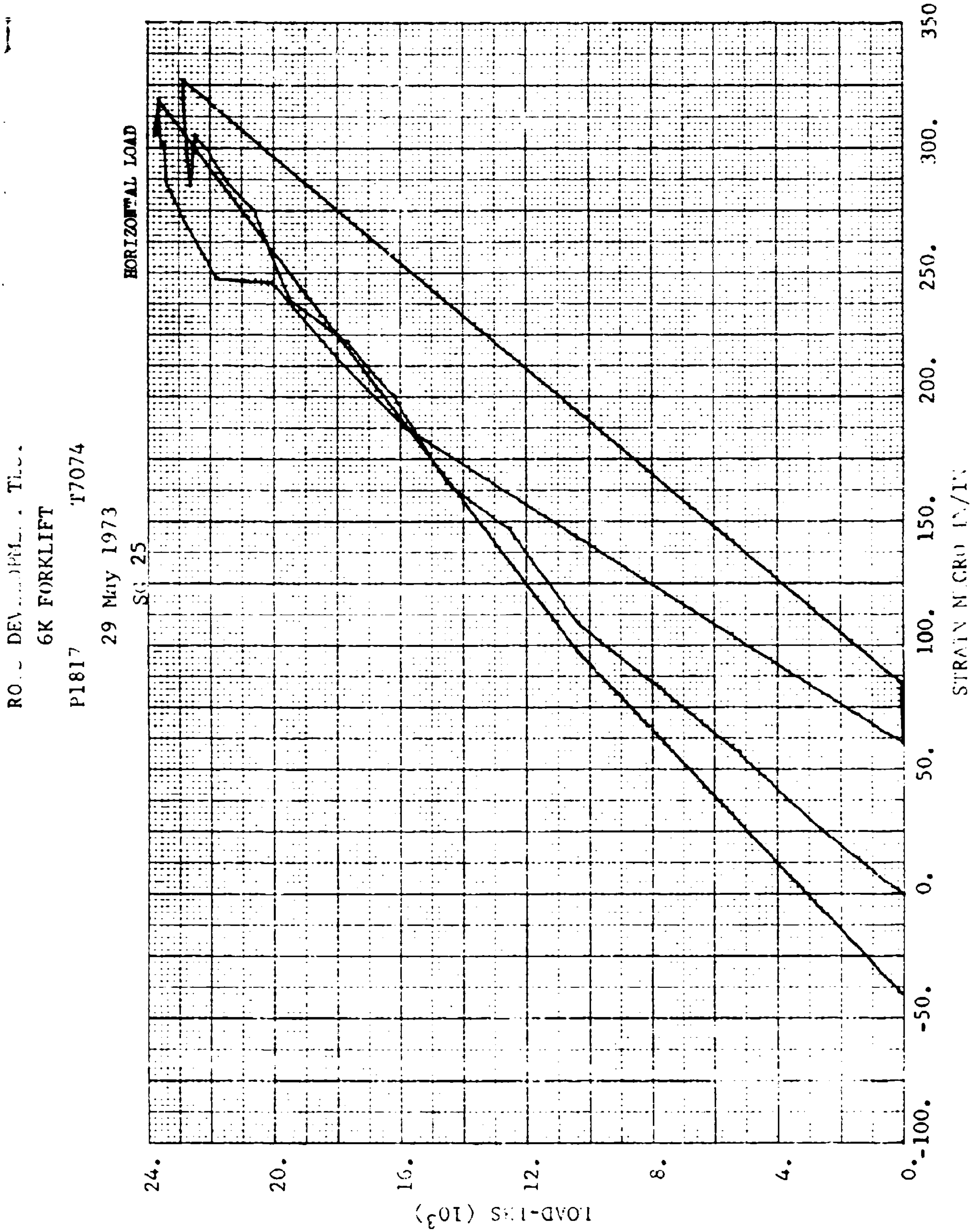


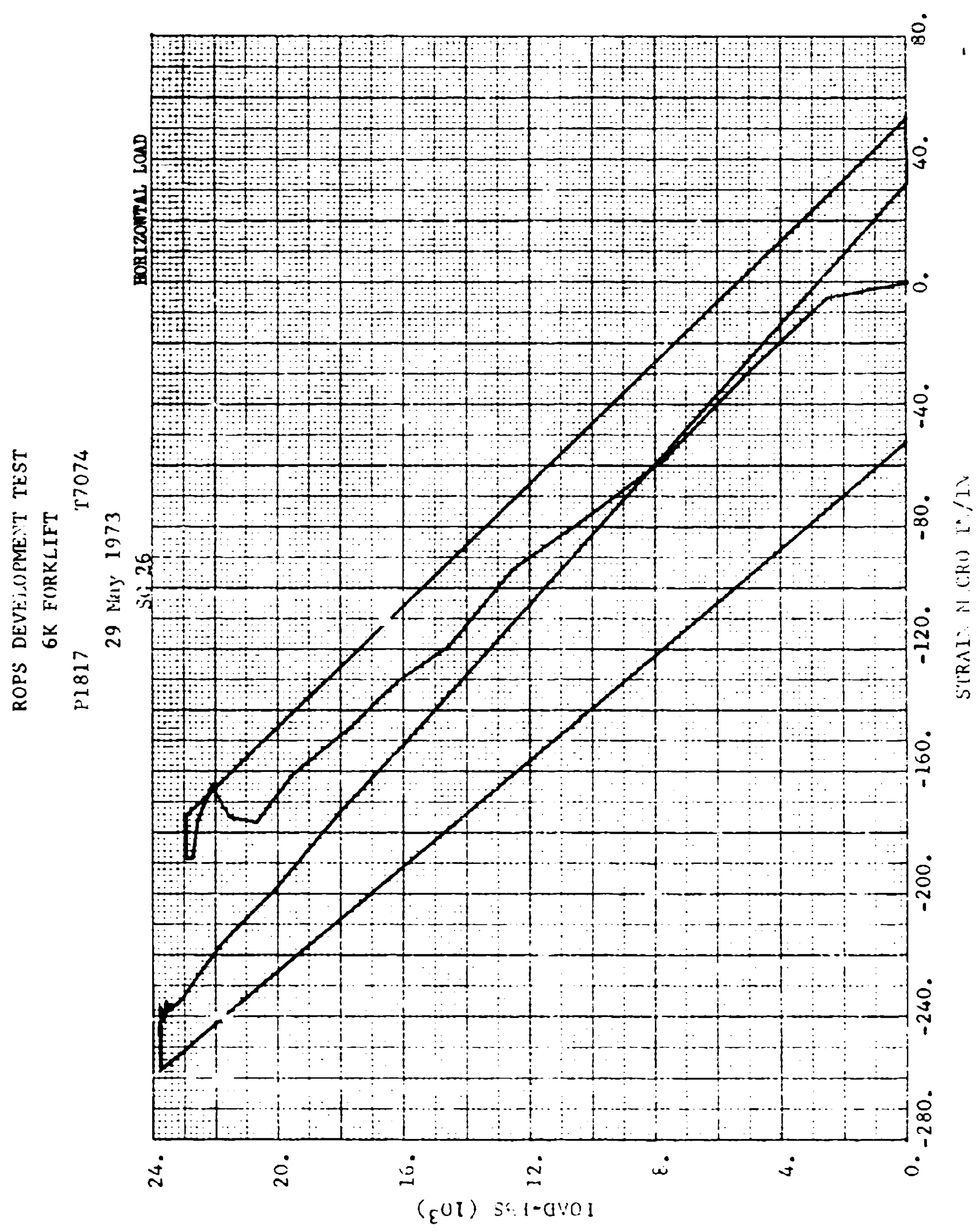

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 22
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
-400.
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.

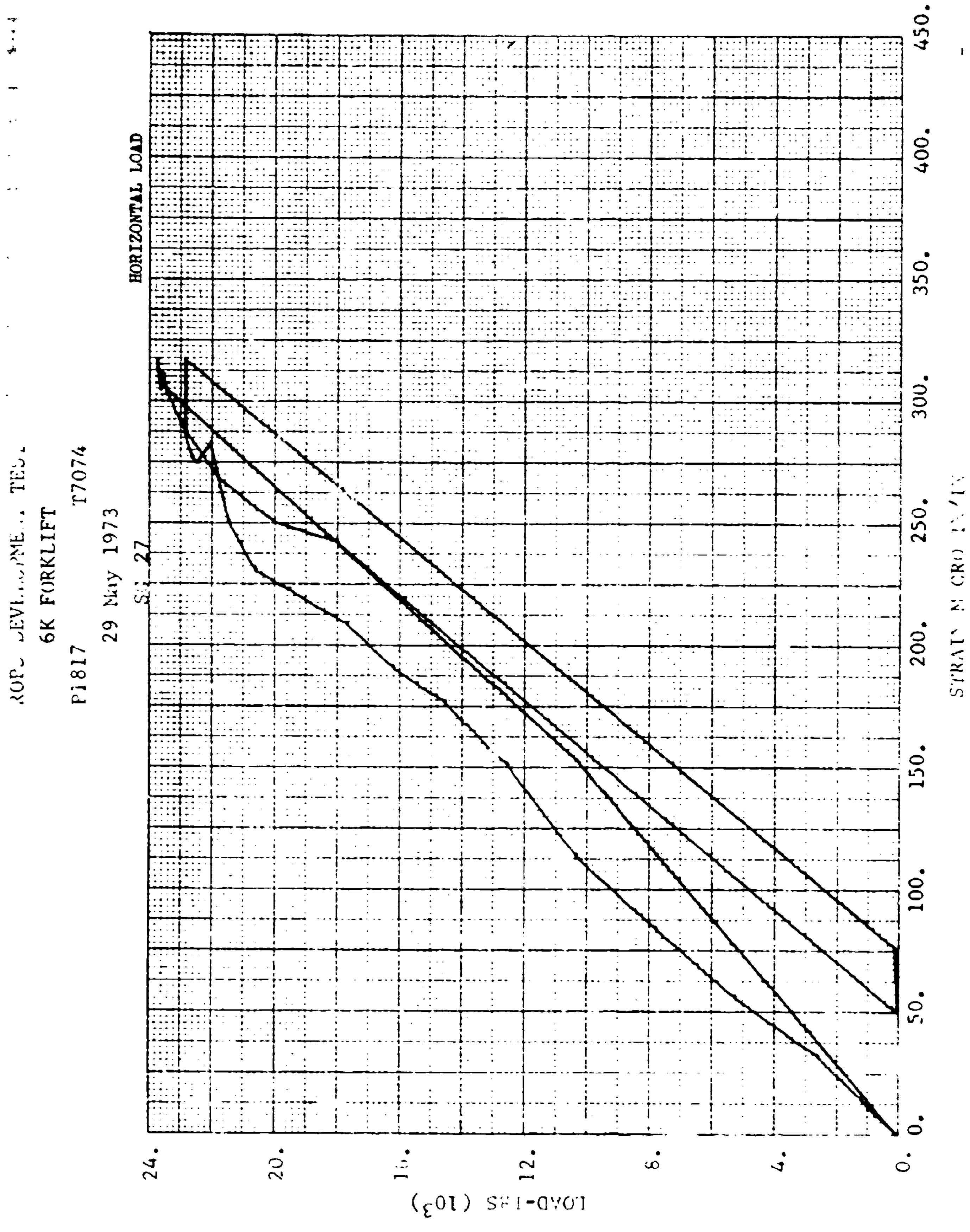
ROTS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 23

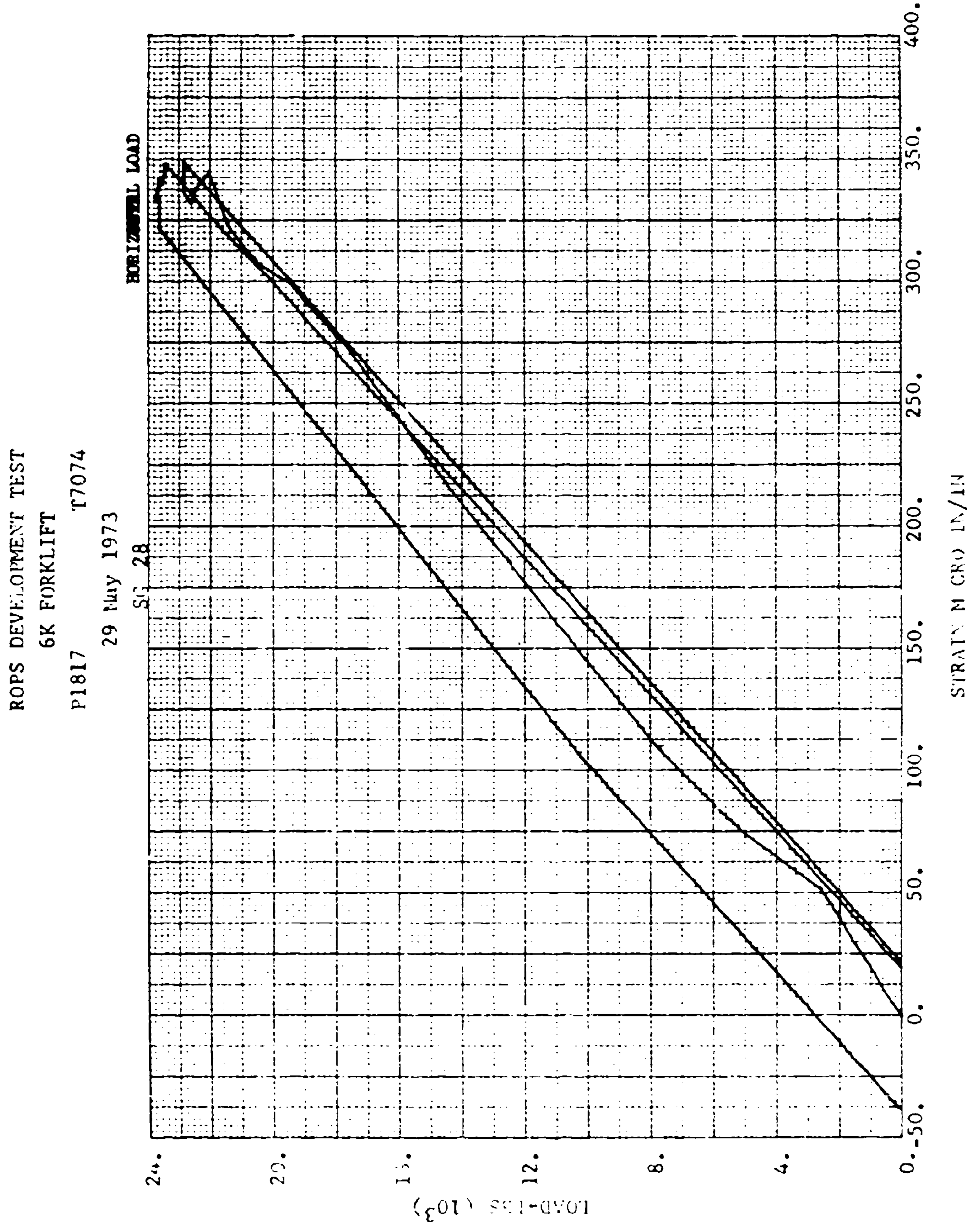


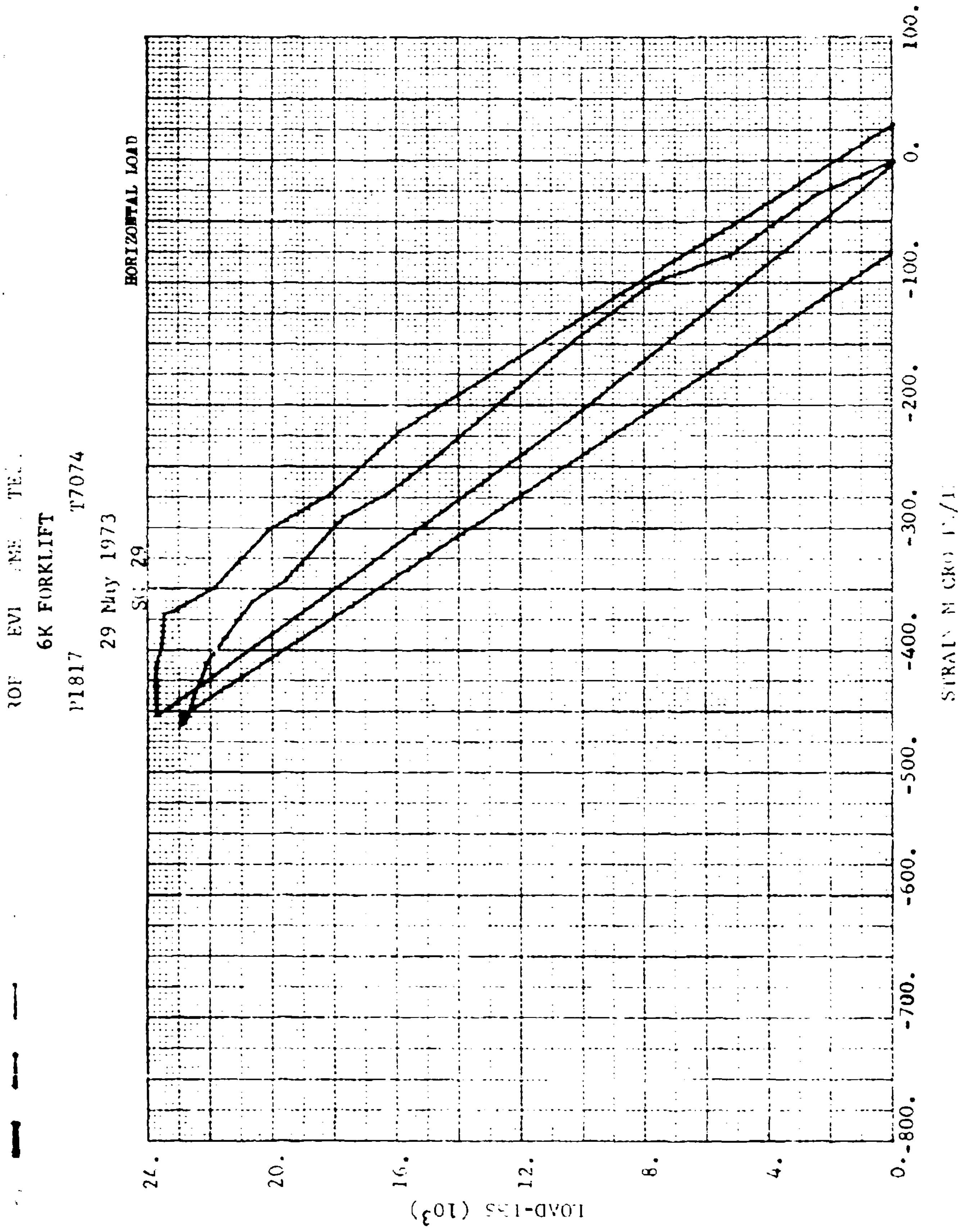

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
400.
0.
-400.
-800.
-1200.
-1600.
-2800.
-3200.
-2400.
24.
20.
12.
8.
4.
0.

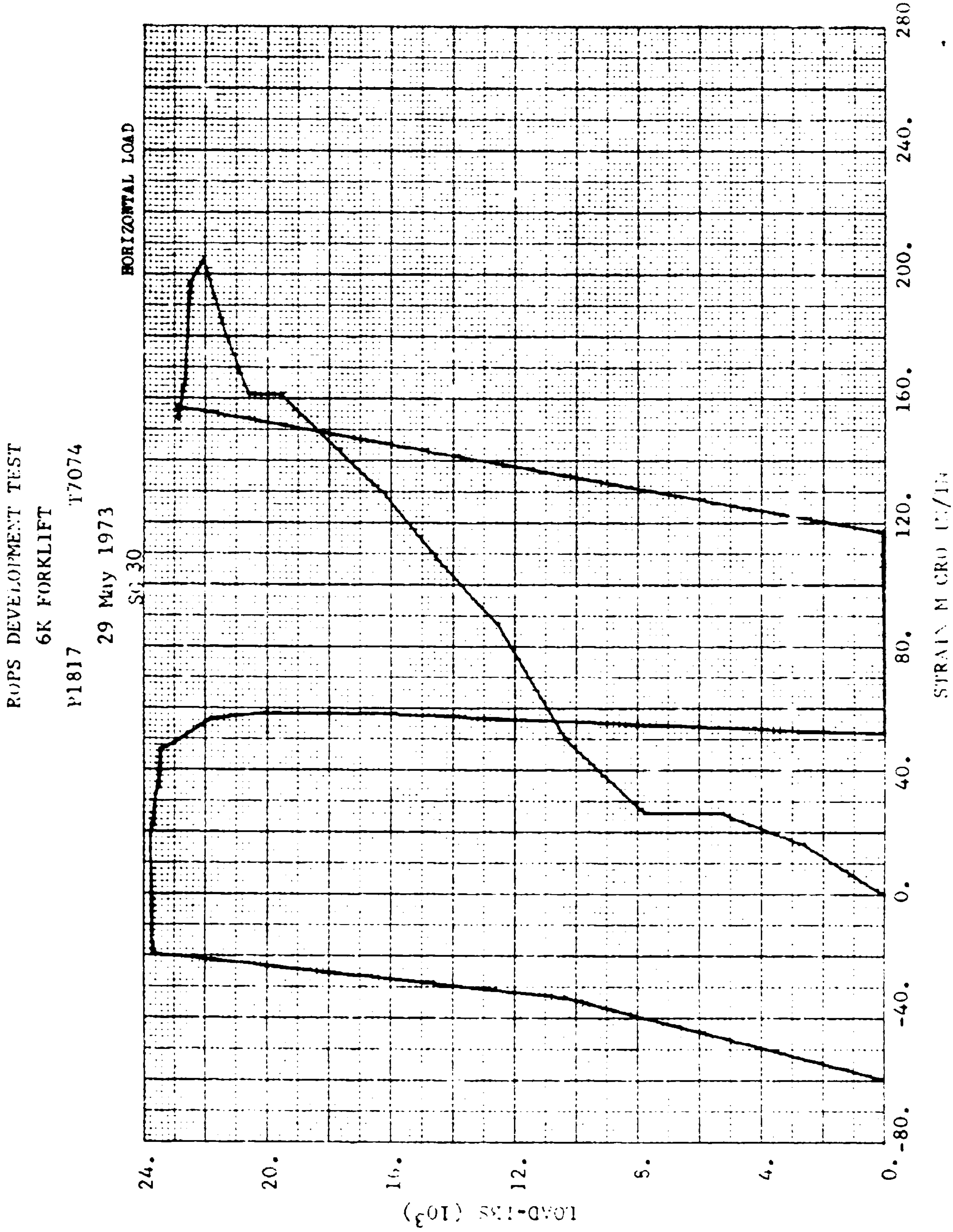

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
350.
300.
250.
200.
150.
100.
50.
0.
-50.
-100.
24.
20.
12.
8.
4.
0.


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 26
HORIZONTAL LOAD
LOAD-LBS (10³)
24. 20. 16. 12. 8. 4. 0.
STRAIN MICRO IN/IN
80. 40. 0. -40. -80. -120. -160. -200. -240. -280.

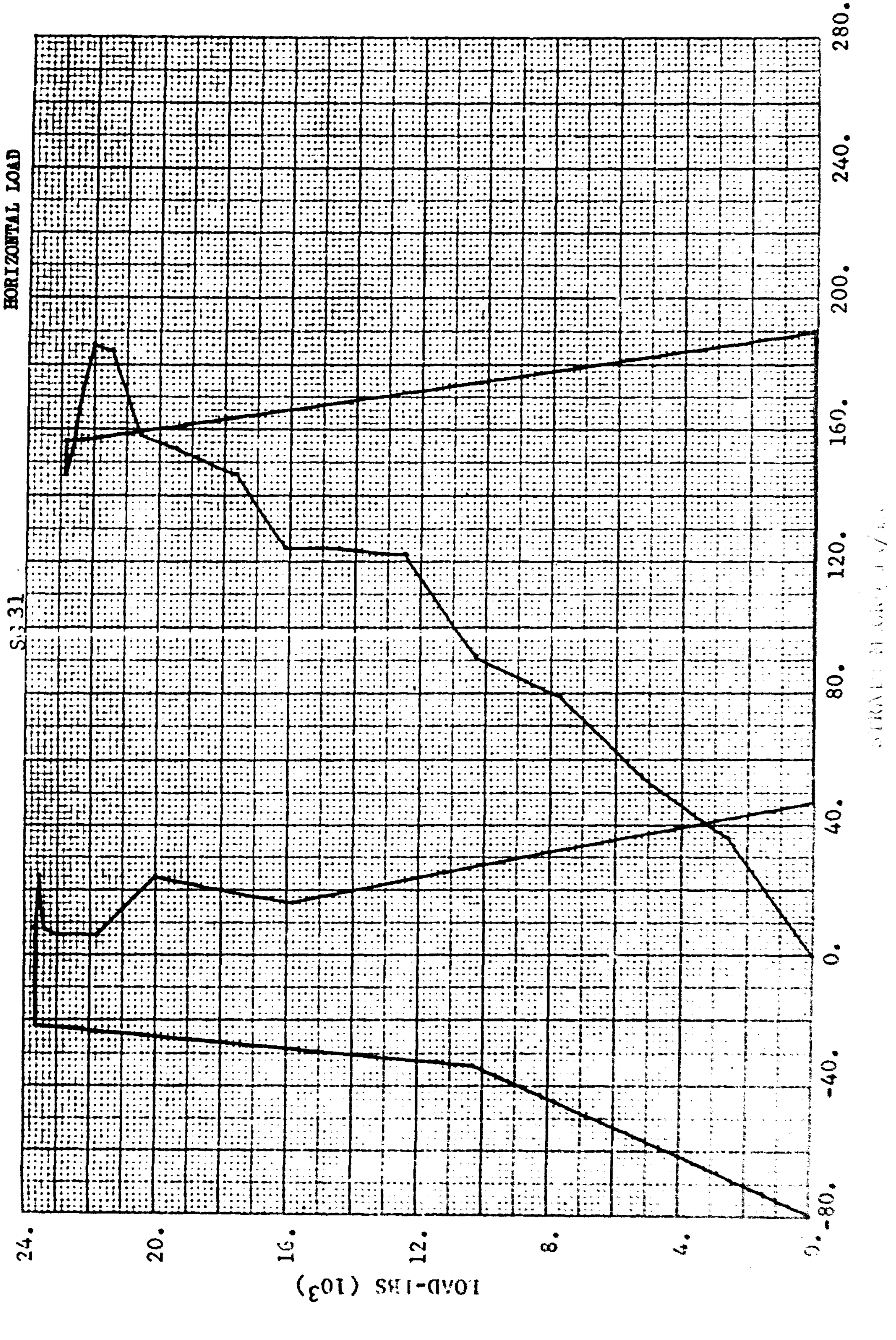

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 27
HORIZONTAL LOAD
STRAIN MICRO IN/IN
0. 50. 100. 150. 200. 250. 300. 350. 400. 450.
LOAD-LBS (10^3)
0. 4. 8. 12. 16. 20. 24.

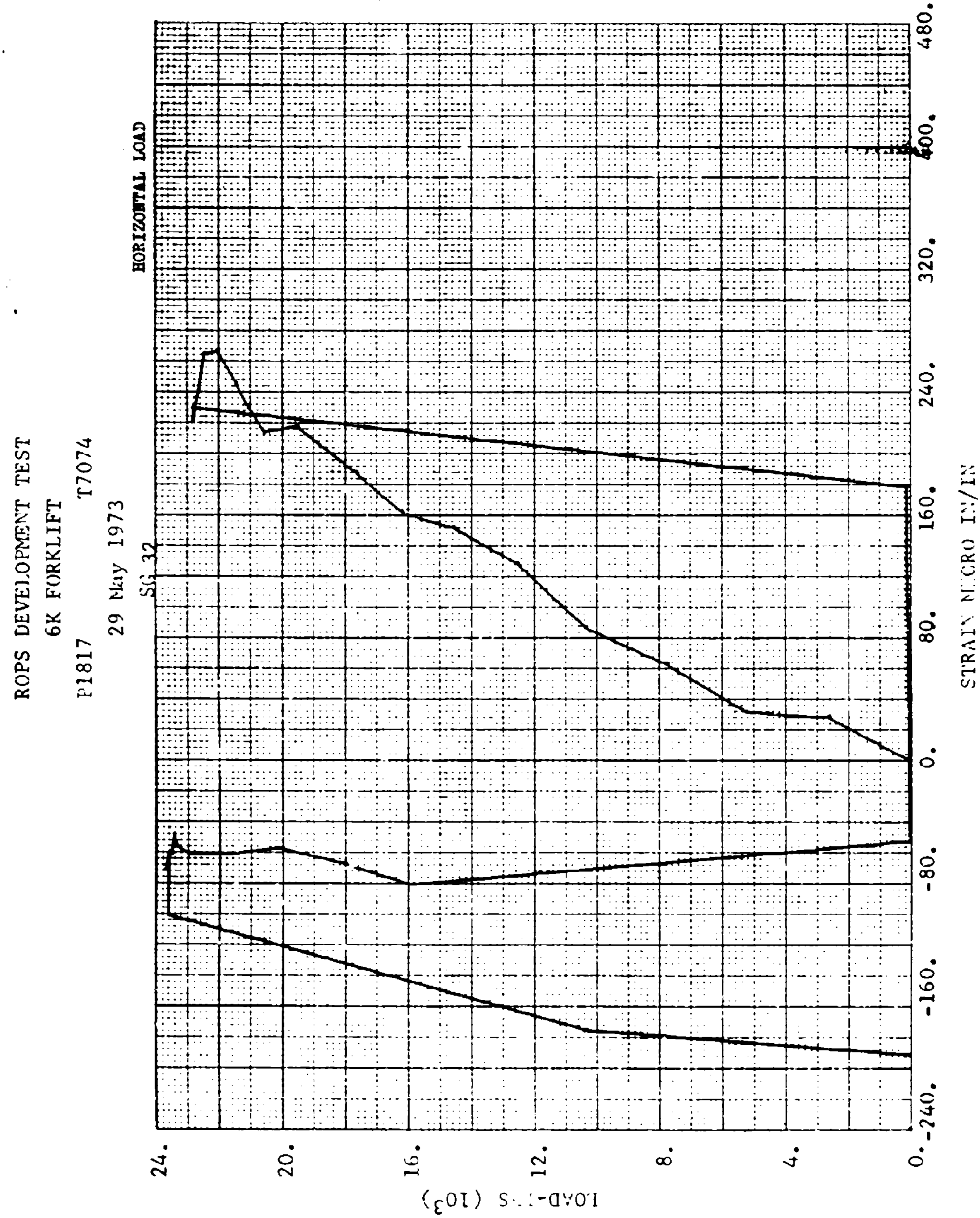

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 28
LOAD
400.
350.
300.
250.
200.
150.
100.
50.
0.
-50.
0.
4.
8.
12.
20.

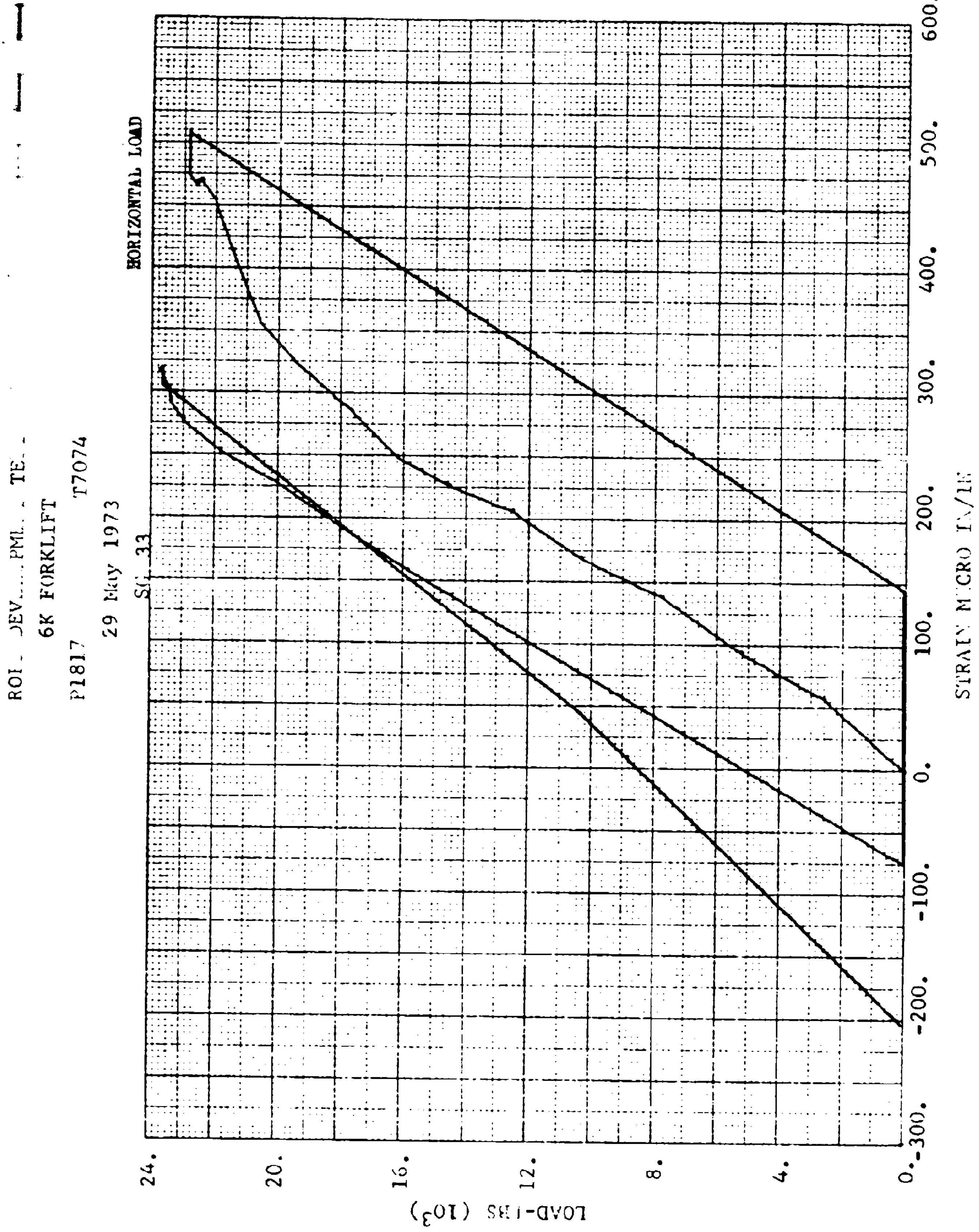

6K FORKLIFT
T7074
29 May 1973
HORIZONTAL LOAD
100.
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
24.
20.
12.
8.
4.
0.


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 30
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
24.
20.
16.
12.
8.
4.
0.
-80.
-40.
0.
40.
80.
120.
160.
200.
240.
280.

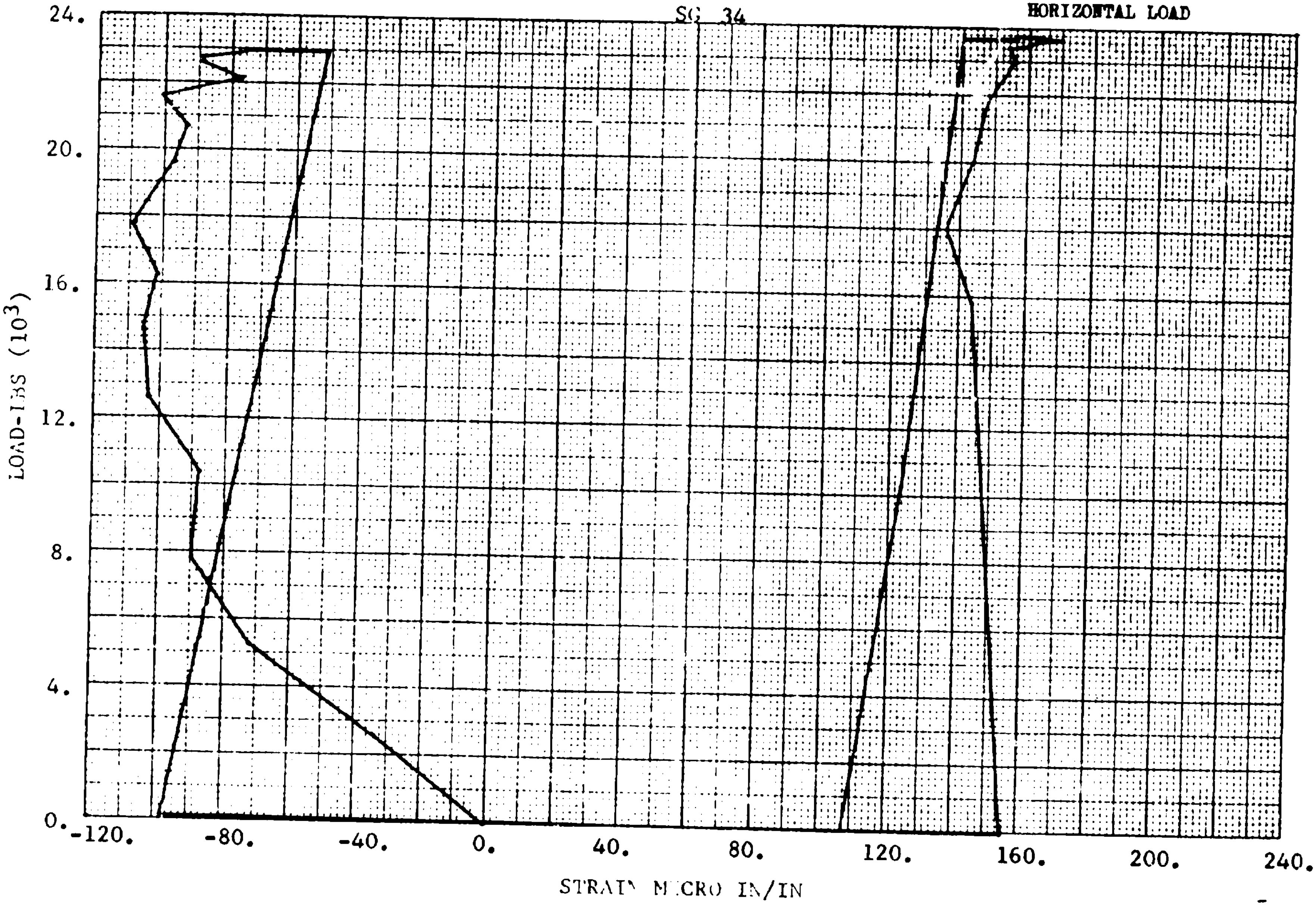
ROE DEVL JPME TEC
6K FORKLIFT
P1817 T7074
29 May 1973
S131



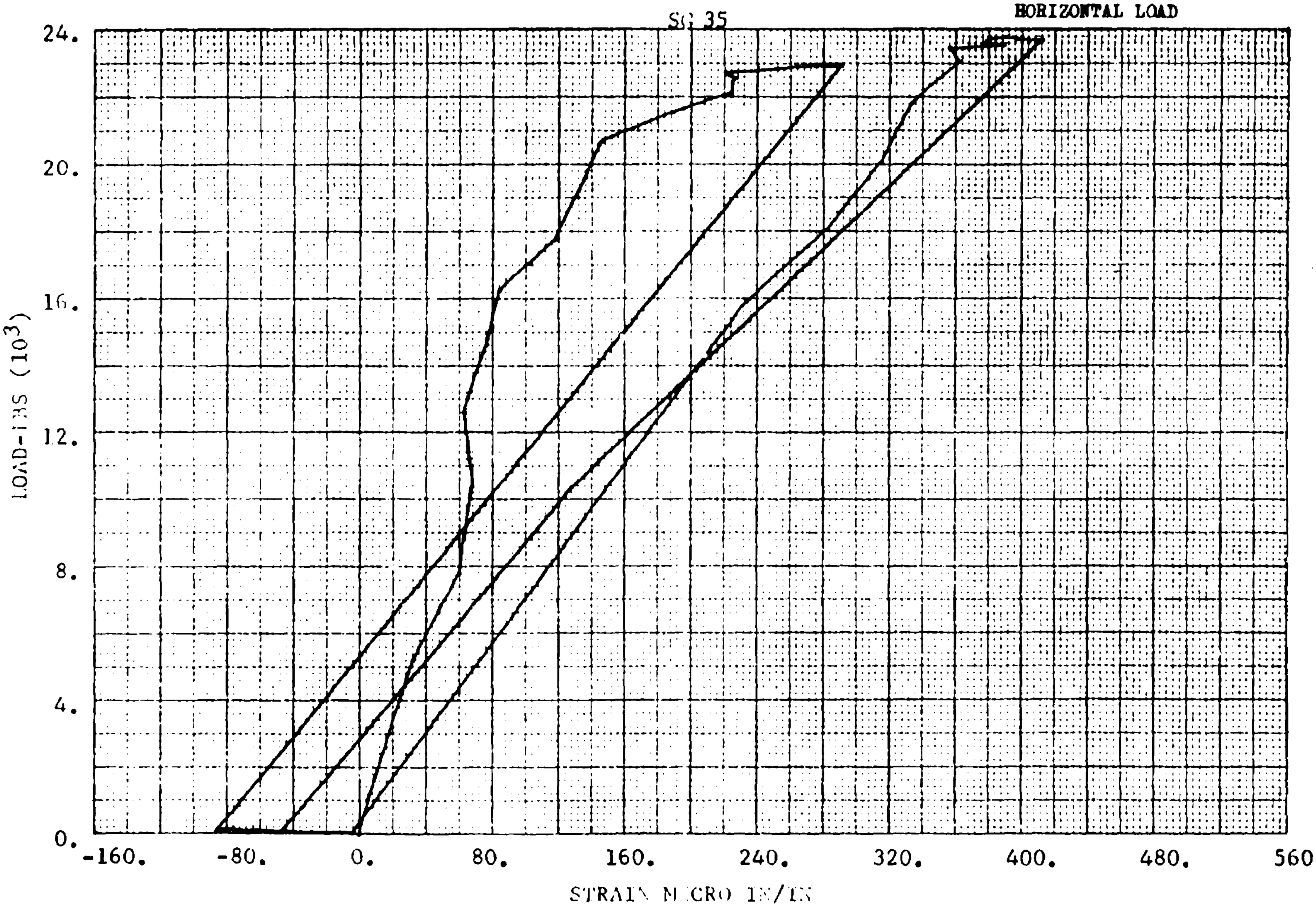

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 32
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
480.
400.
320.
240.
160.
80.
0.
-80.
-160.
-240.
24.
20.
16.
12.
8.
4.
0.


6K FORKLIFT
P1817
T7074
29 May 1973
HORIZONTAL LOAD
24.
20.
16.
12.
8.
4.
0.
-300.
-200.
-100.
0.
100.
200.
300.
400.
500.
600.
LOAD-LBS (10^3)

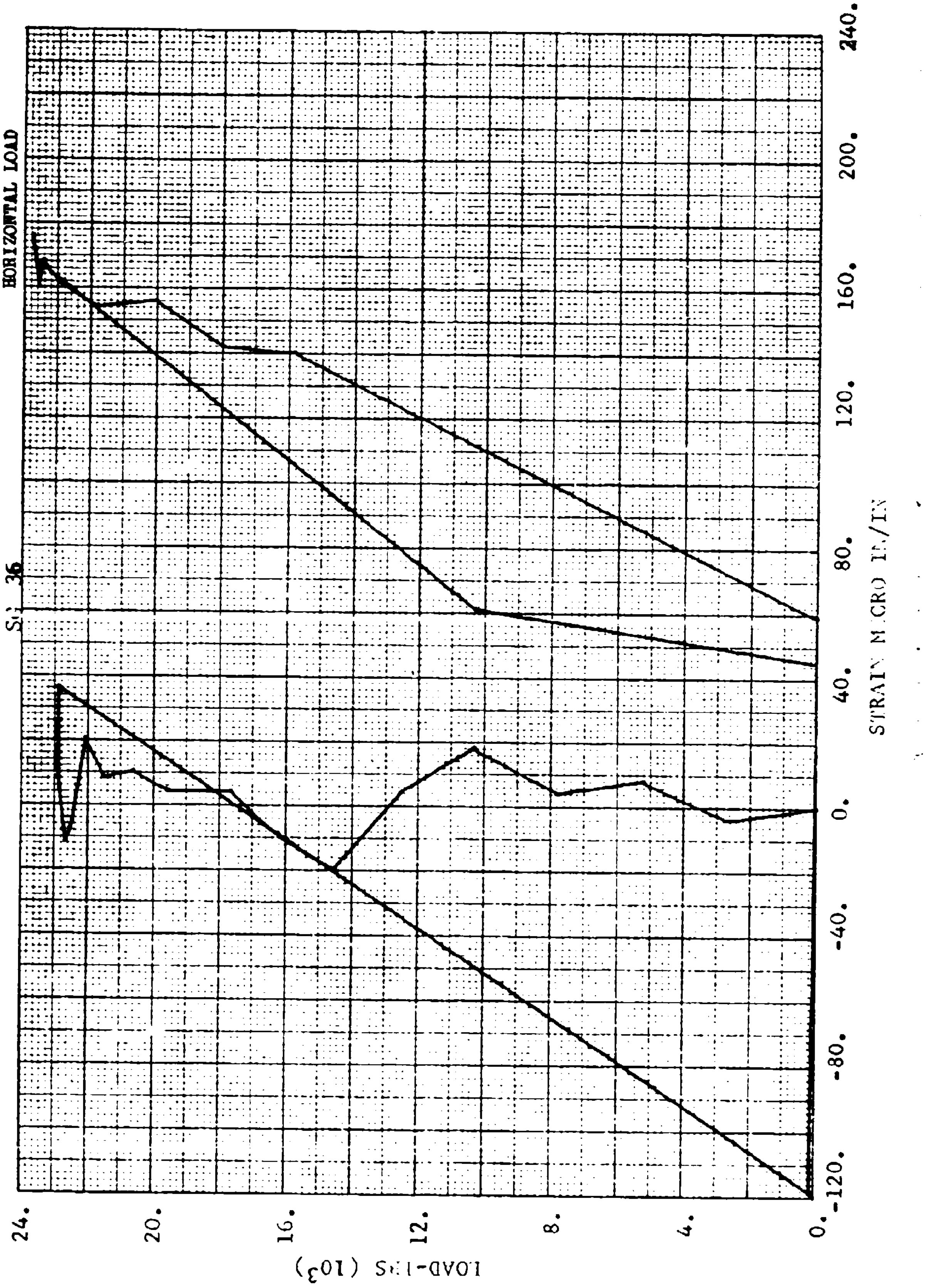
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



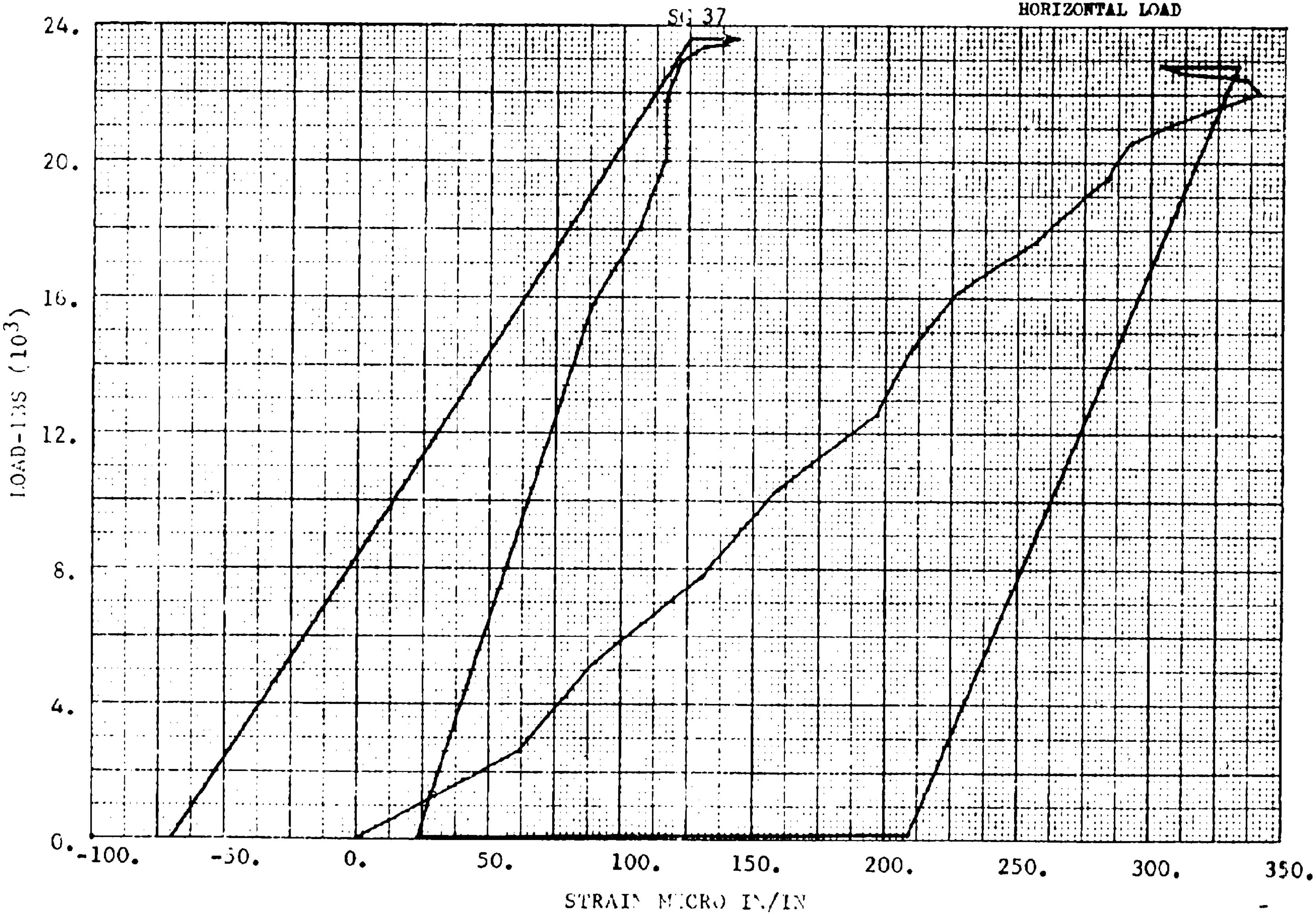
ROF DEVL PME TE
6K FORKLIFT
P1817 T7074
29 May 1973
SG 35

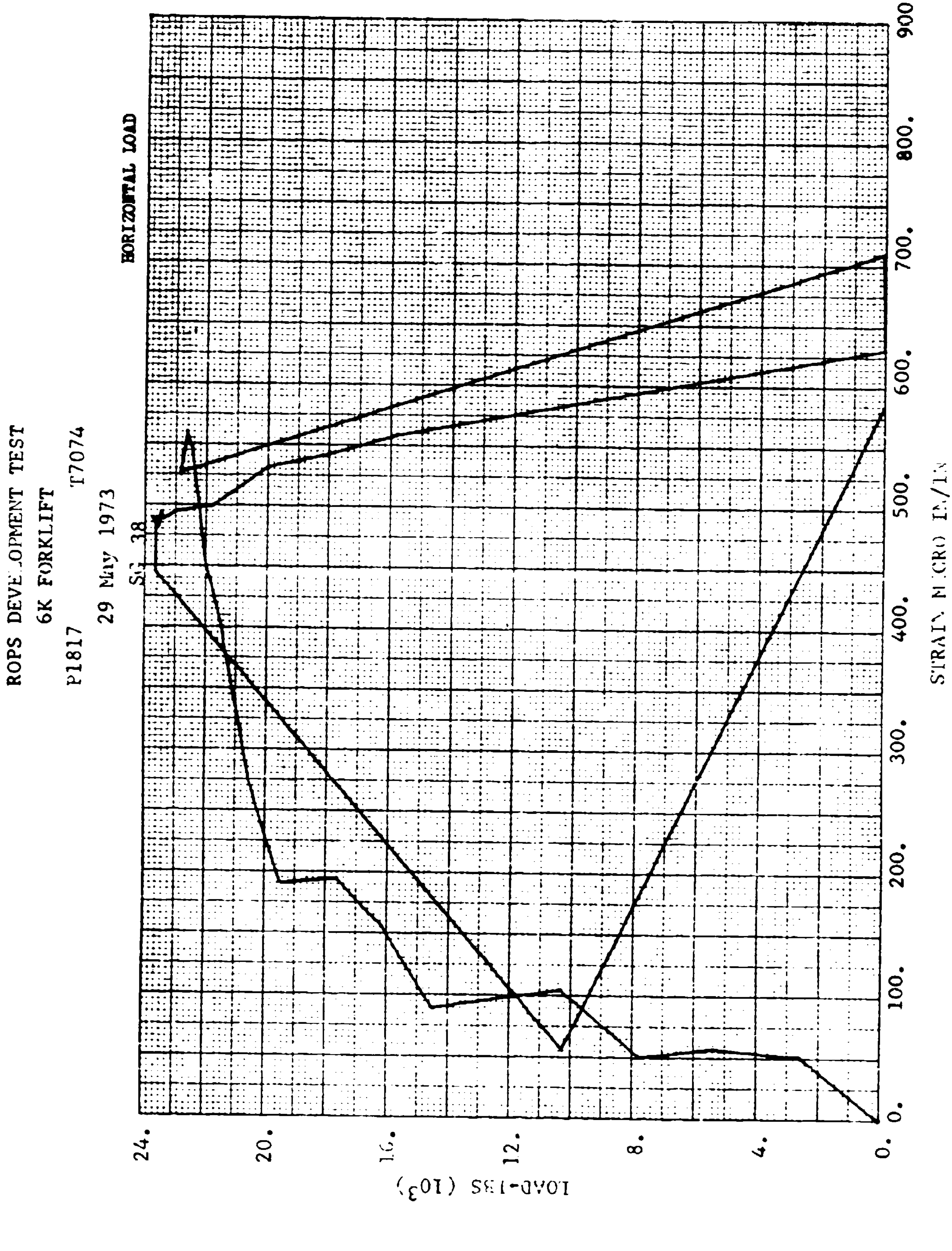


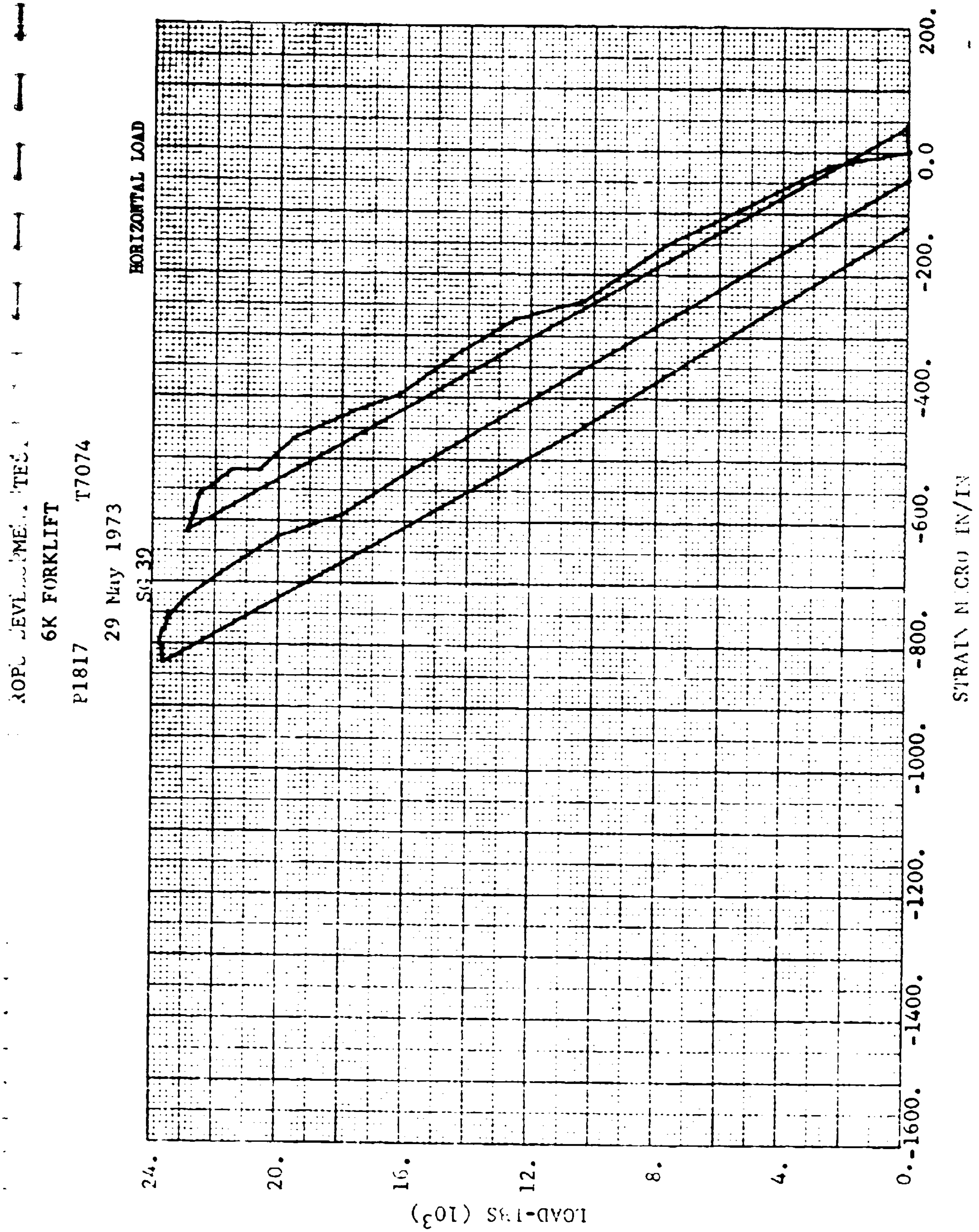
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 36



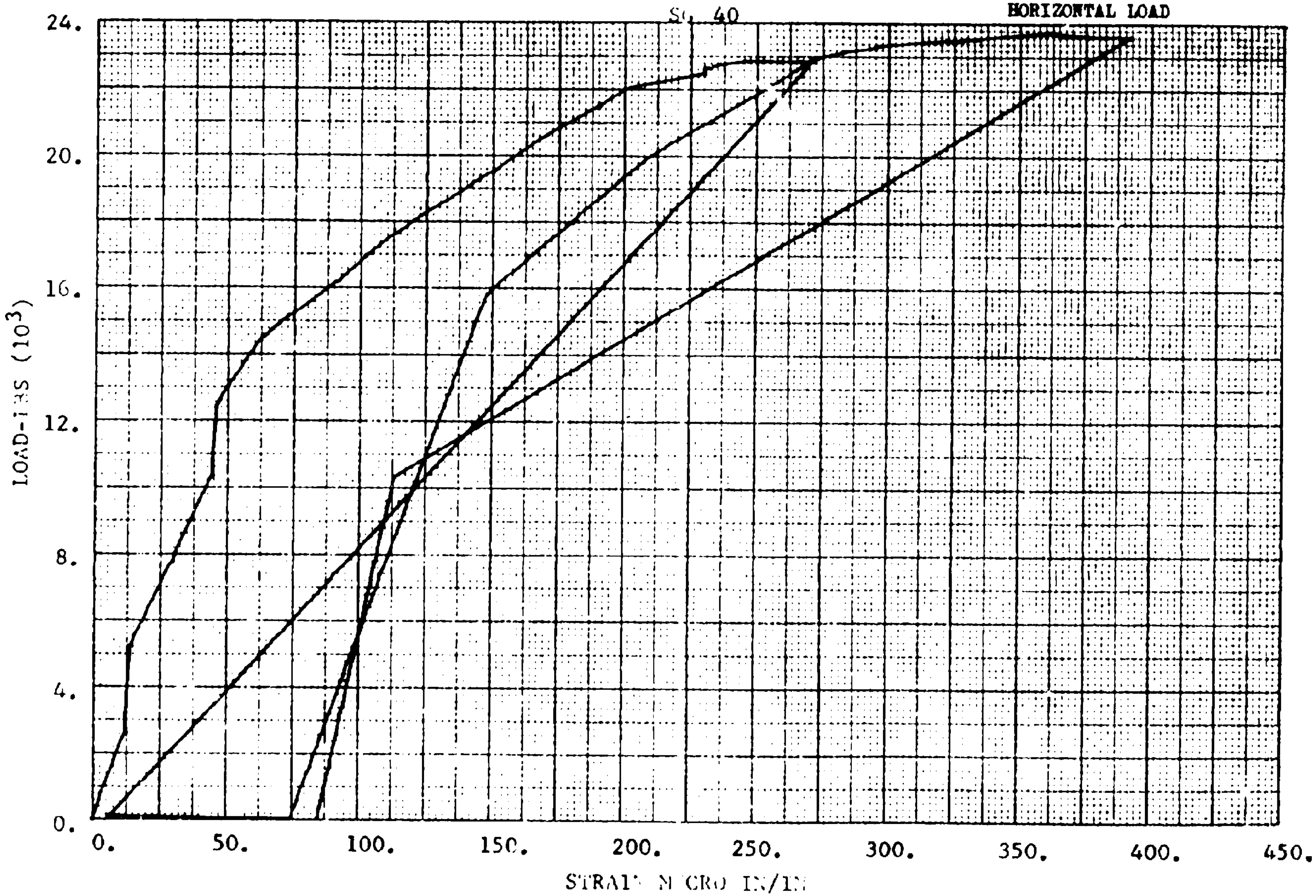
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973




ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 38
HORIZONTAL LOAD
LOAD-LBS (10^3)
STRAIN MICRO IN/IN
0.
4.
8.
12.
16.
20.
24.
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.


6K FORKLIFT
P1817
T7074
29 May 1973
HORIZONTAL LOAD
200.
0.0
-200.
-400.
-600.
-800.
-1000.
-1200.
-1400.
-1600.
24.
20.
16.
12.
8.
4.
0.

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



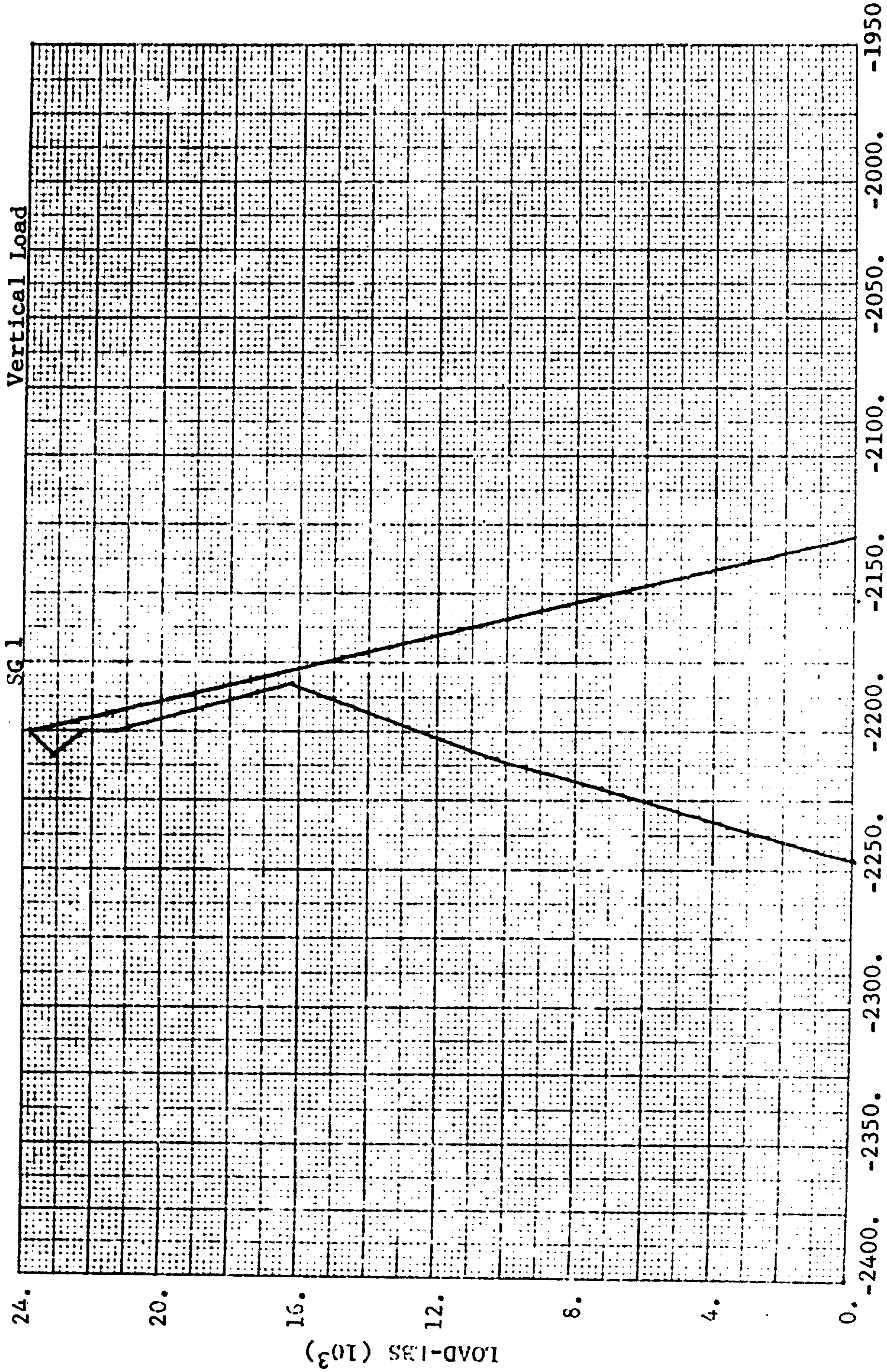
TR-684-059

ADDENDUM II

PLOTS OF STRAIN VERSUS LOAD

DURING VERTICAL LOADING

ROPS DEVELOPMENT TEST
6K FORKLIFT
F1817 27074
29 May 1973
SG 1



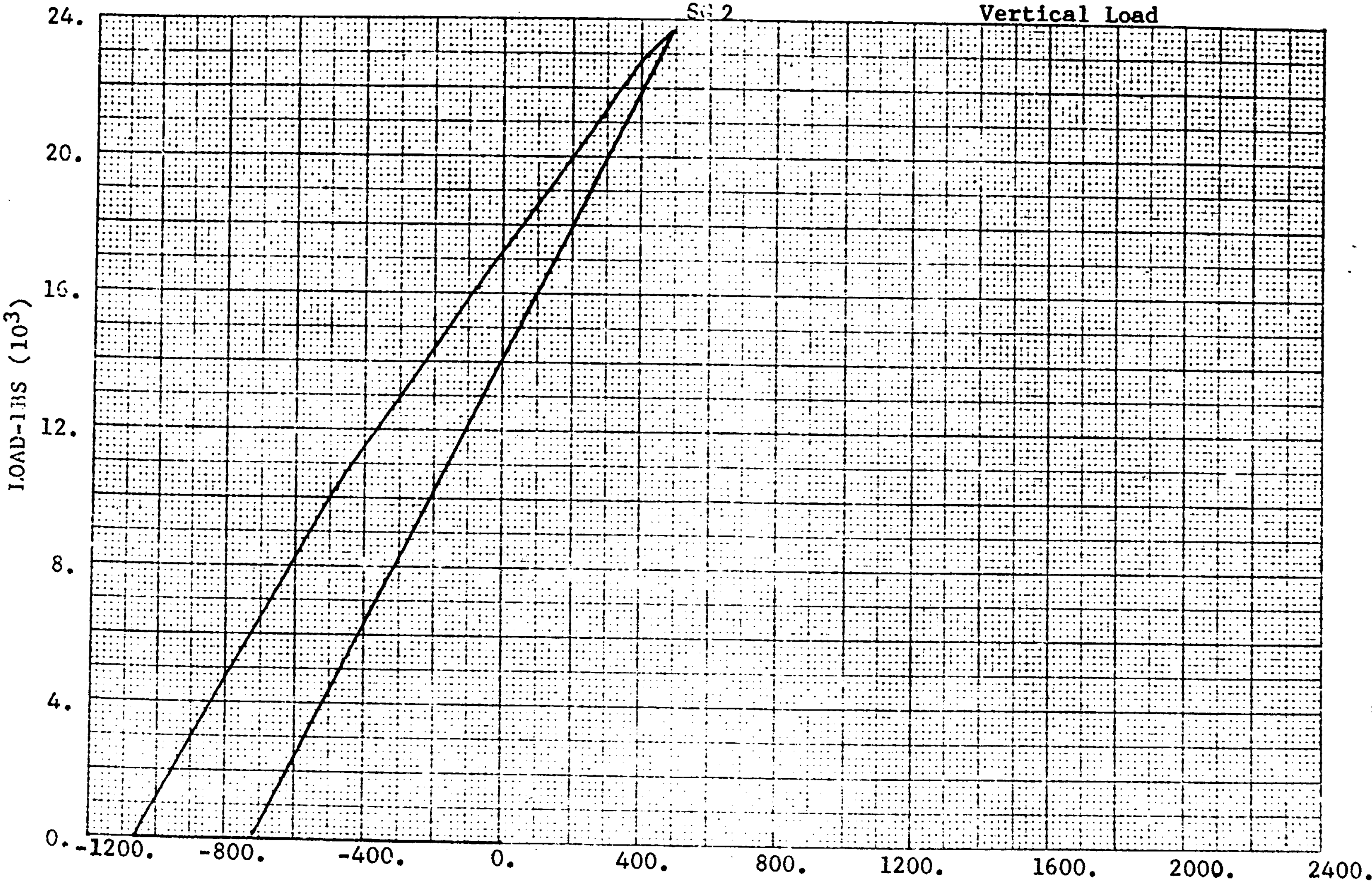
[illegible]ROB[illegible] DEVE[illegible]PME[illegible] TE[illegible]

6K FORKLIFT

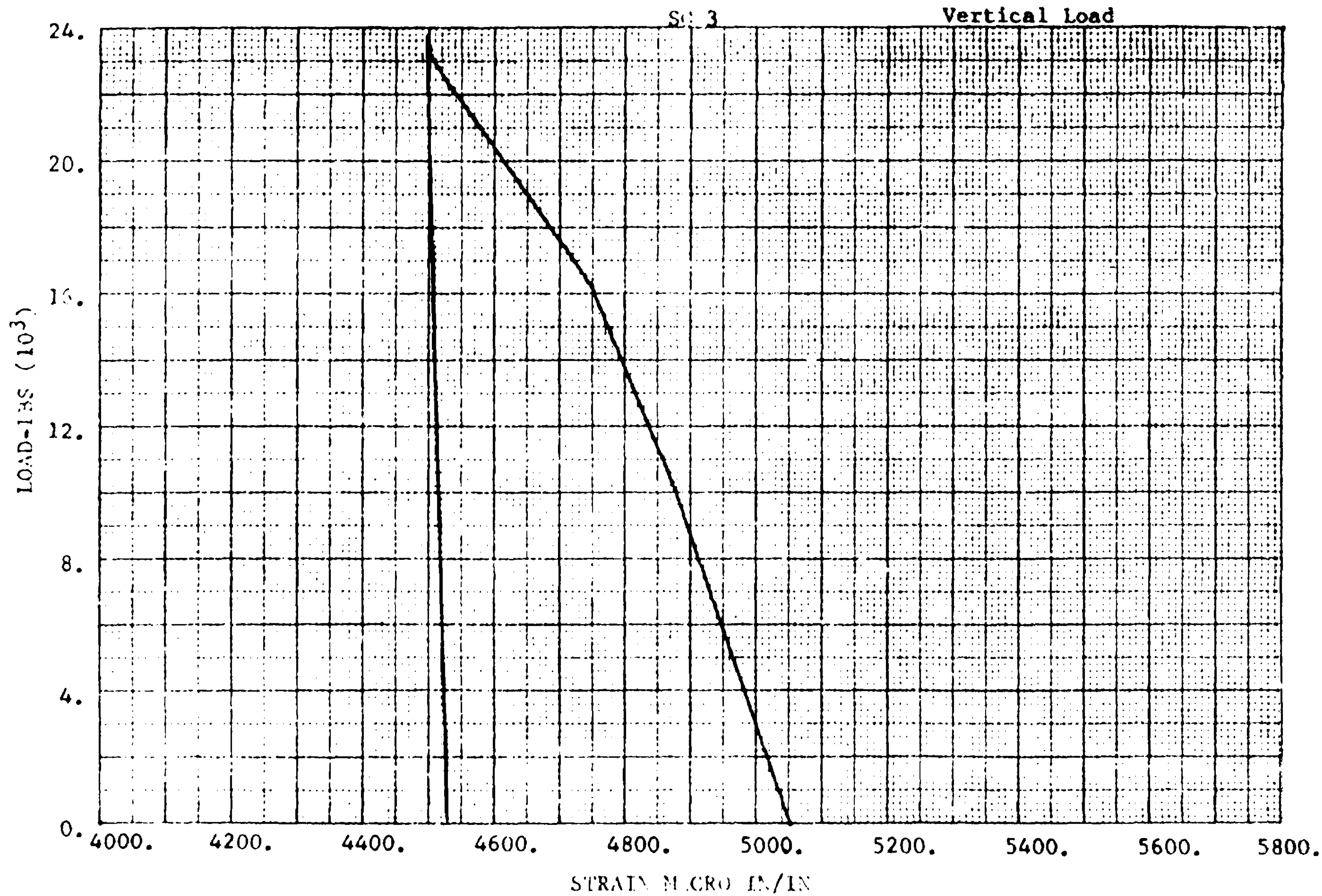
F1817 F7074

29 May 1973

SG 2 Vertical Load



ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 3

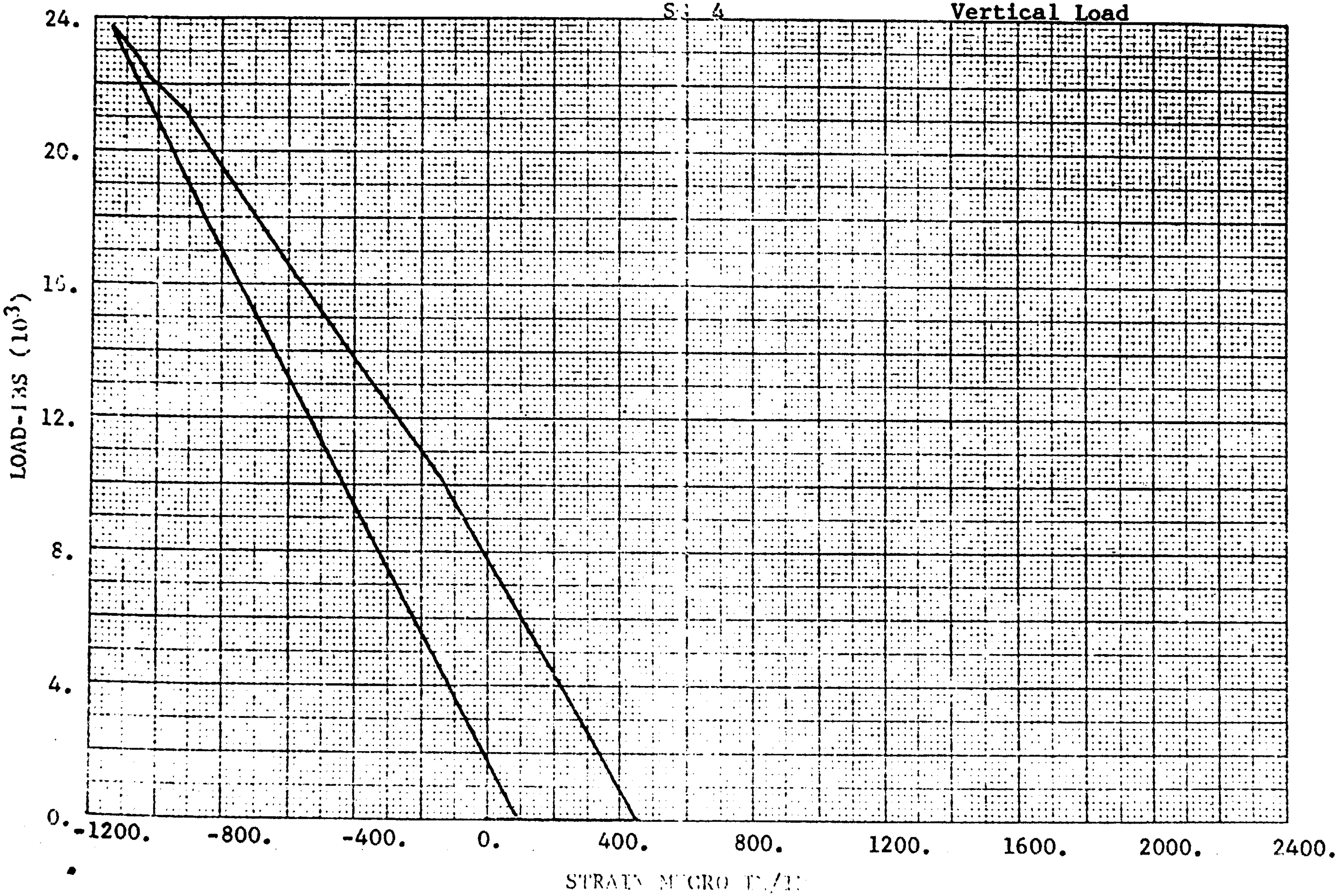


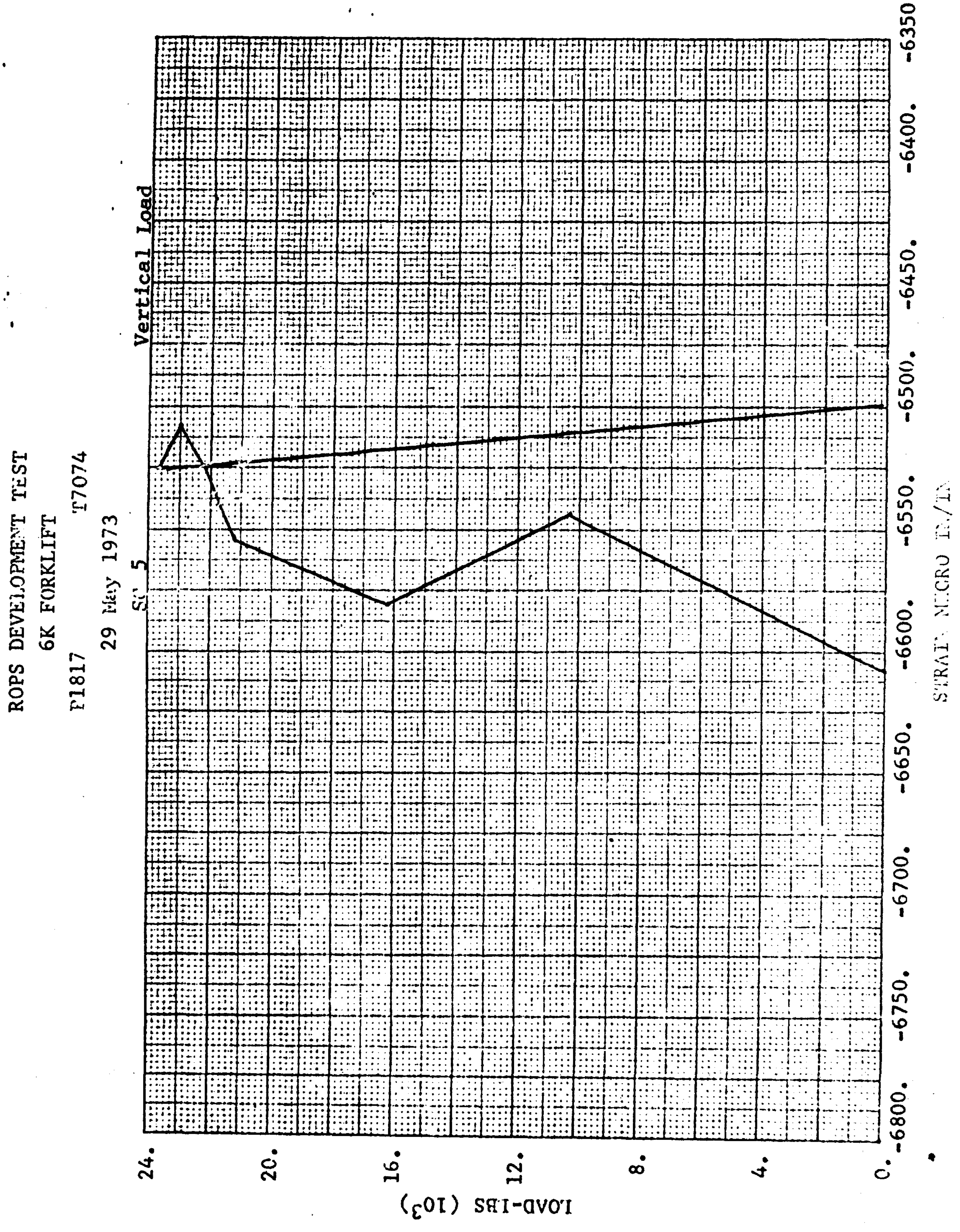
6K FORKLIFT

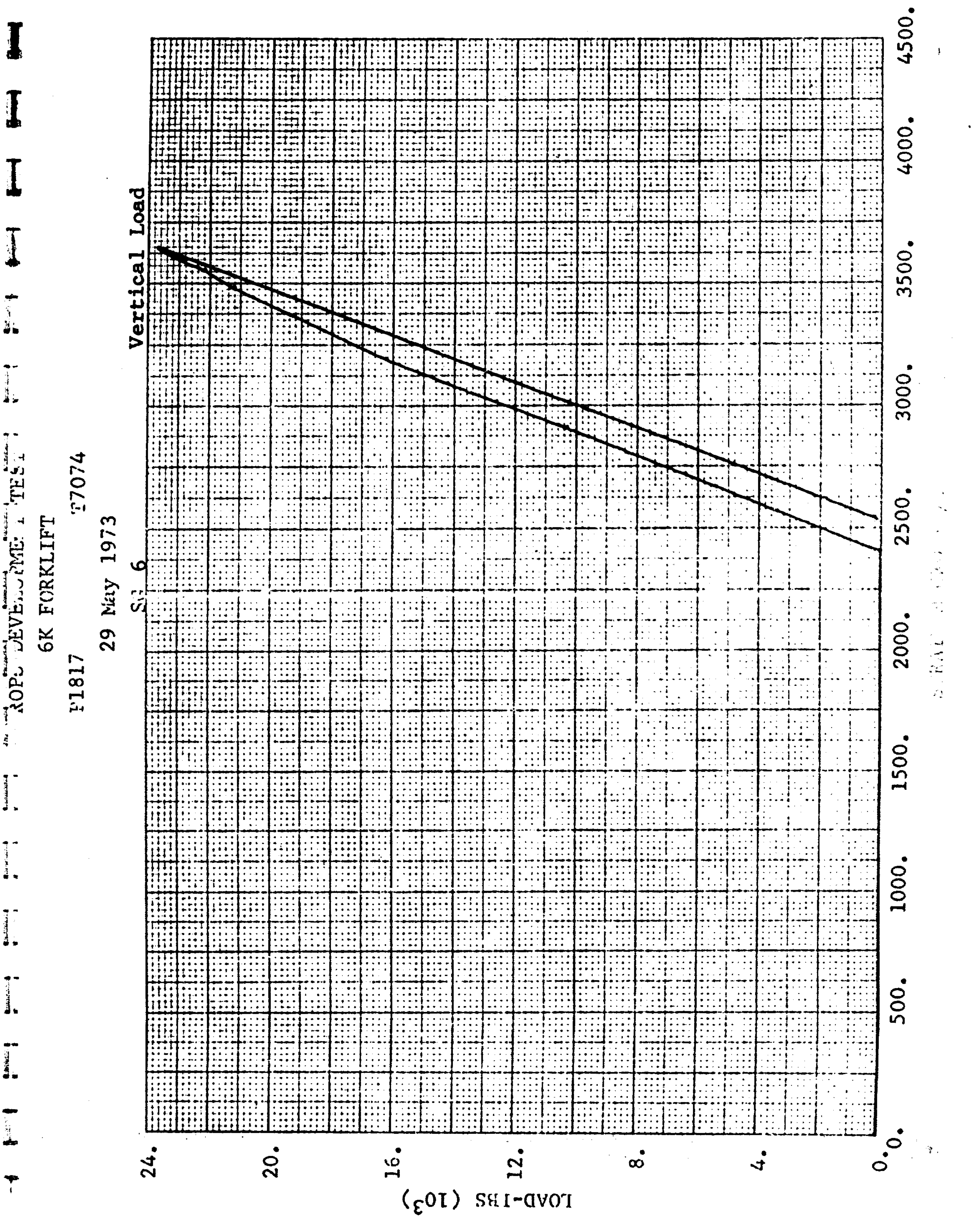
P1817 T7074

29 May 1973

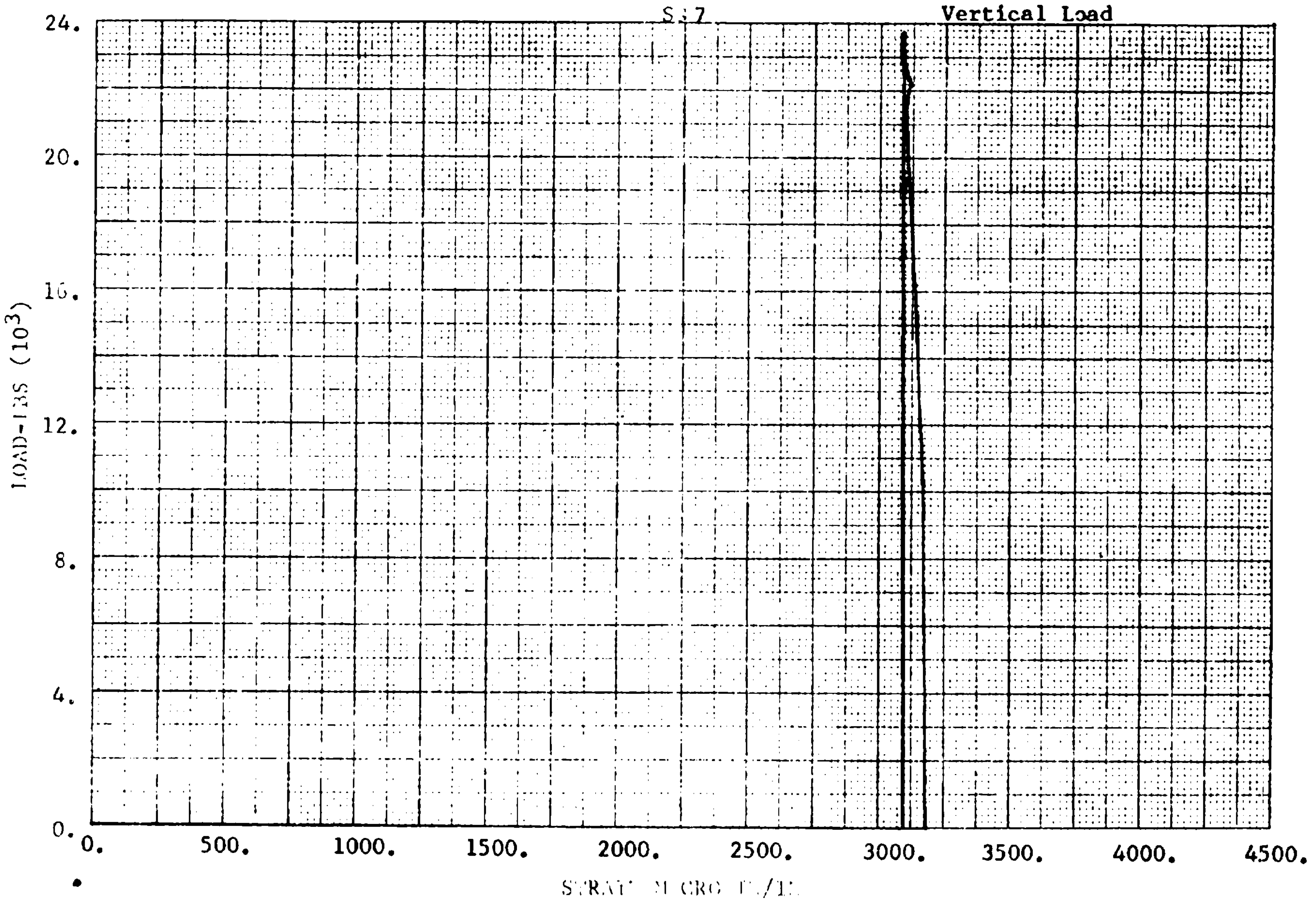
S: 4 Vertical Load



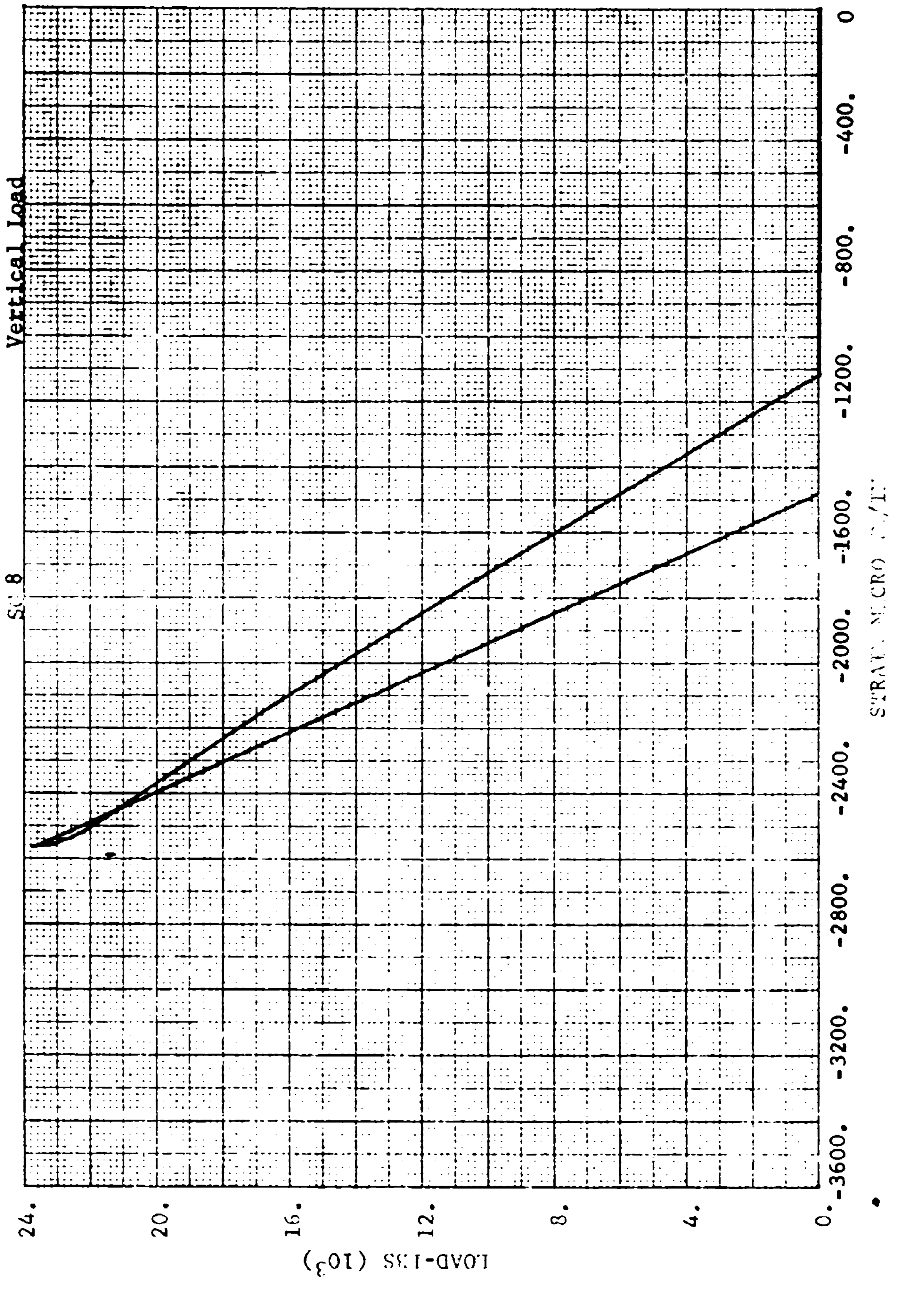

ROPS DEVELOPMENT TEST
6K FORKLIFT
F1817 T7074
29 May 1973
SG 5
Vertical Load
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)
-6350.
-6400.
-6450.
-6500.
-6550.
-6600.
-6650.
-6700.
-6750.
-6800.
STRAIN MICRO IN/IN


6K FORKLIFT
F1817 T7074
29 May 1973
Vertical Load
0. 500. 1000. 1500. 2000. 2500. 3000. 3500. 4000. 4500.
0.0 4. 8. 12. 16. 20. 24.
LOAD-LBS (10³)

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973



ROF DEVT PME ITEM
6K FORKLIFT
P1817 T7074
29 May 1973
SG 8



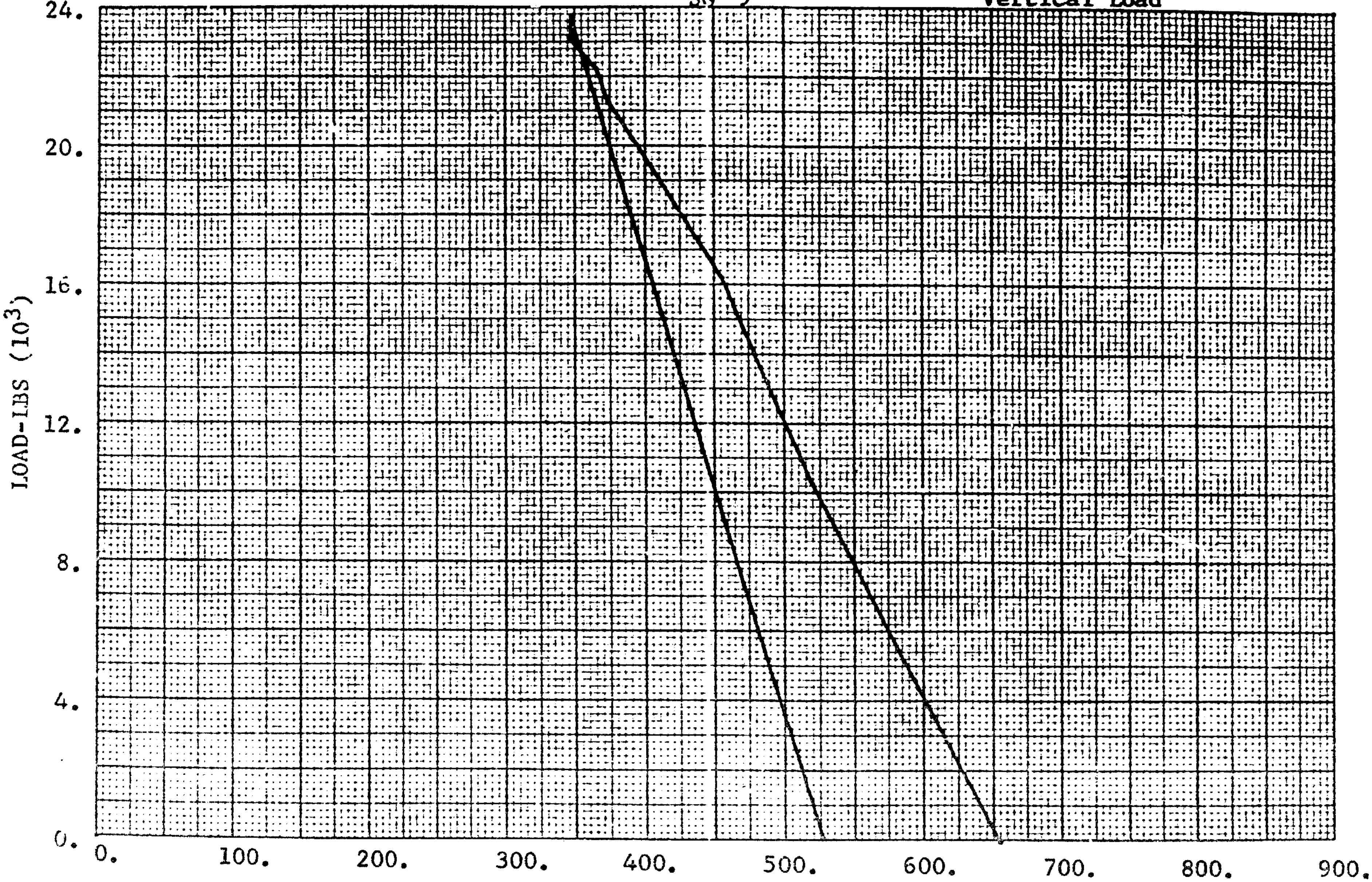
ROPS DEVELOPMENT TEST

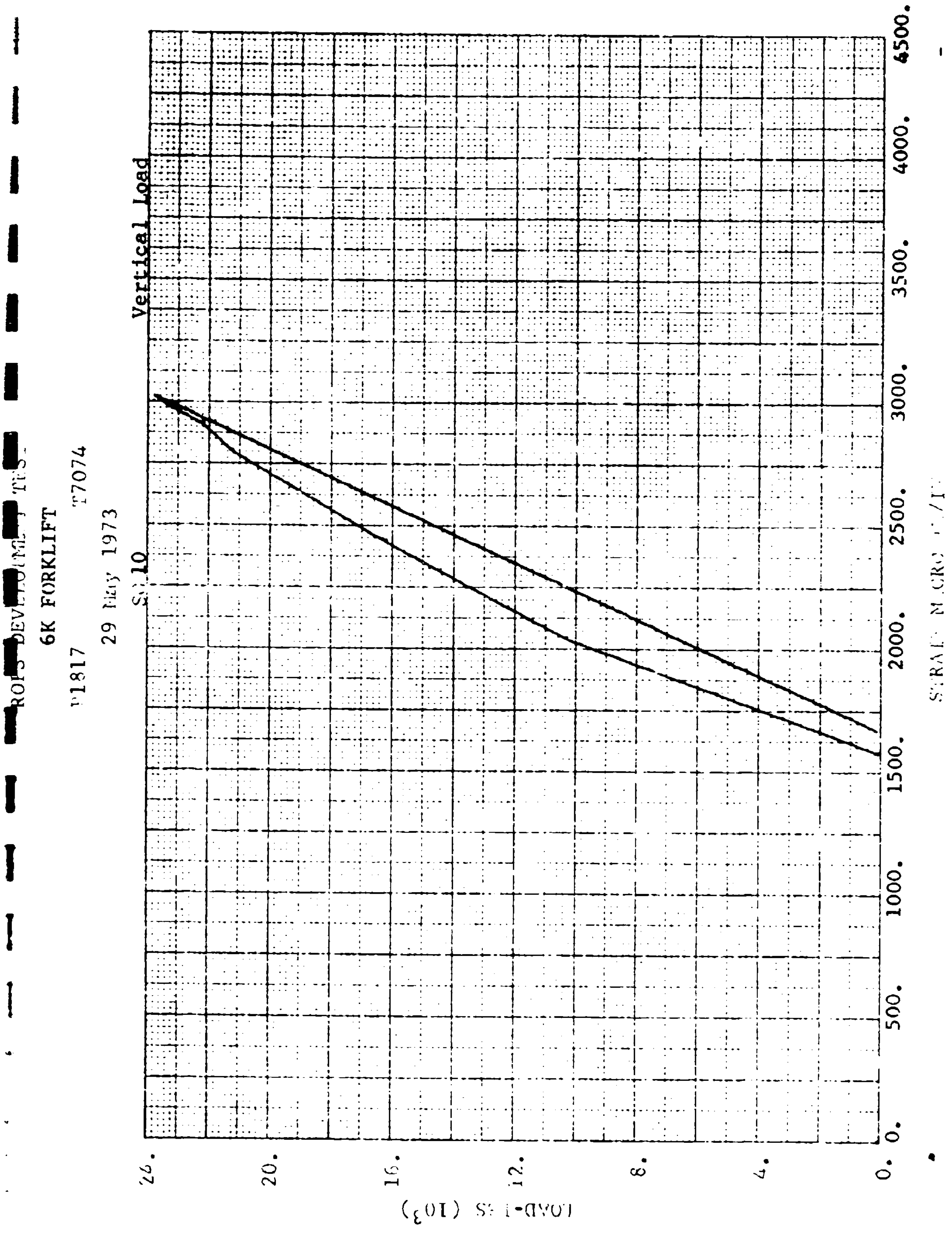
6K FORKLIFT

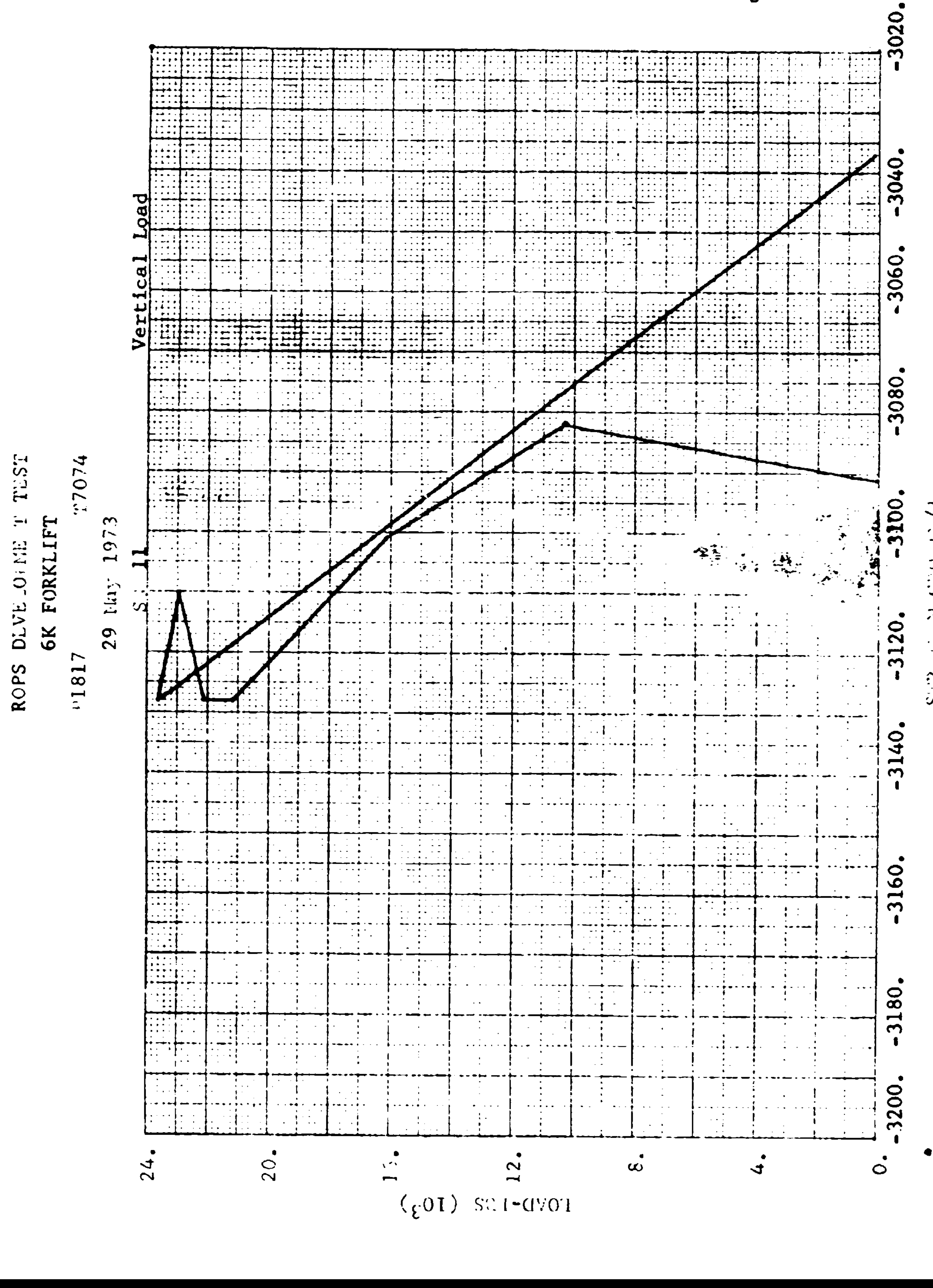
P1817 T7074

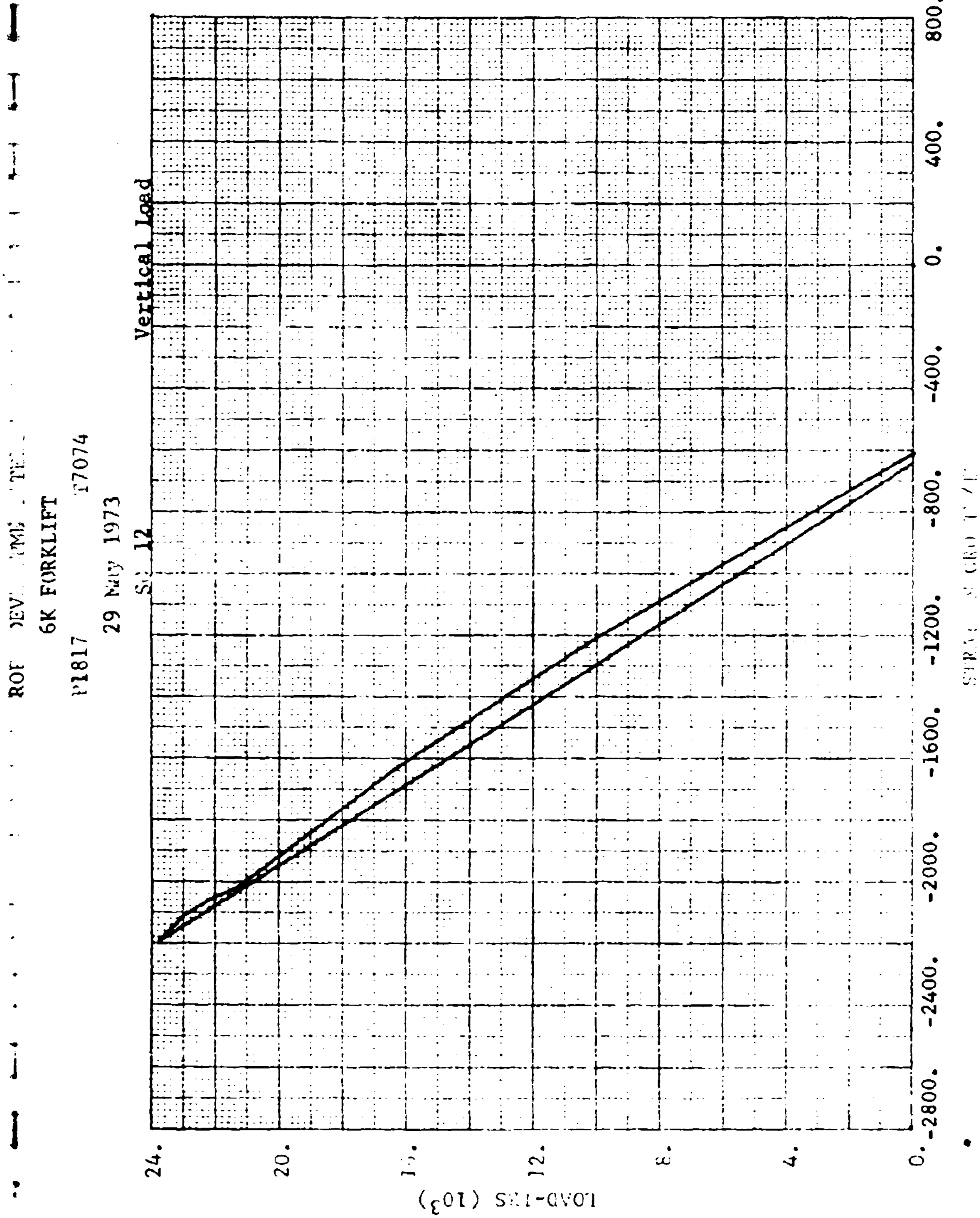
29 May 1973

SG 9 Vertical Load

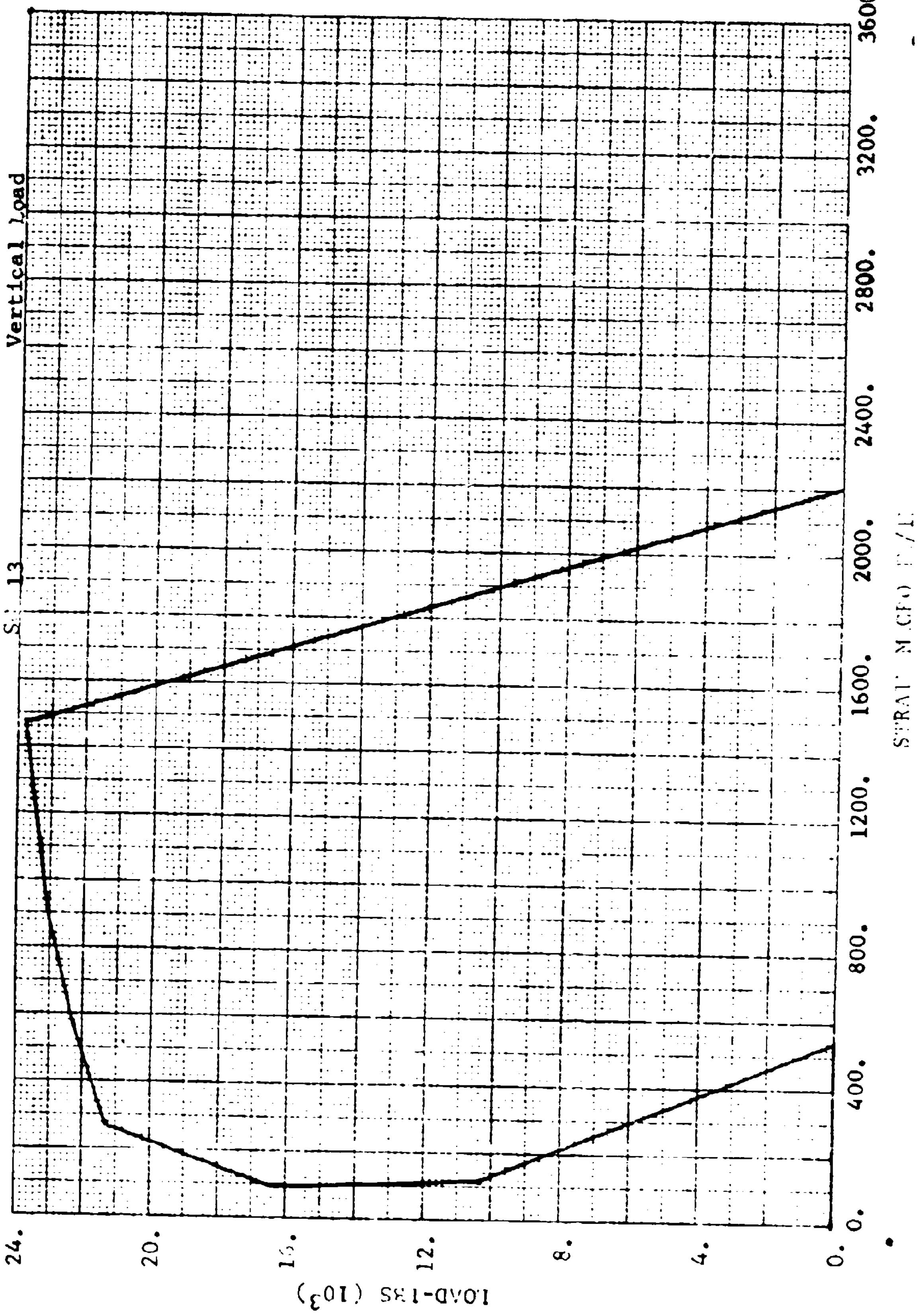


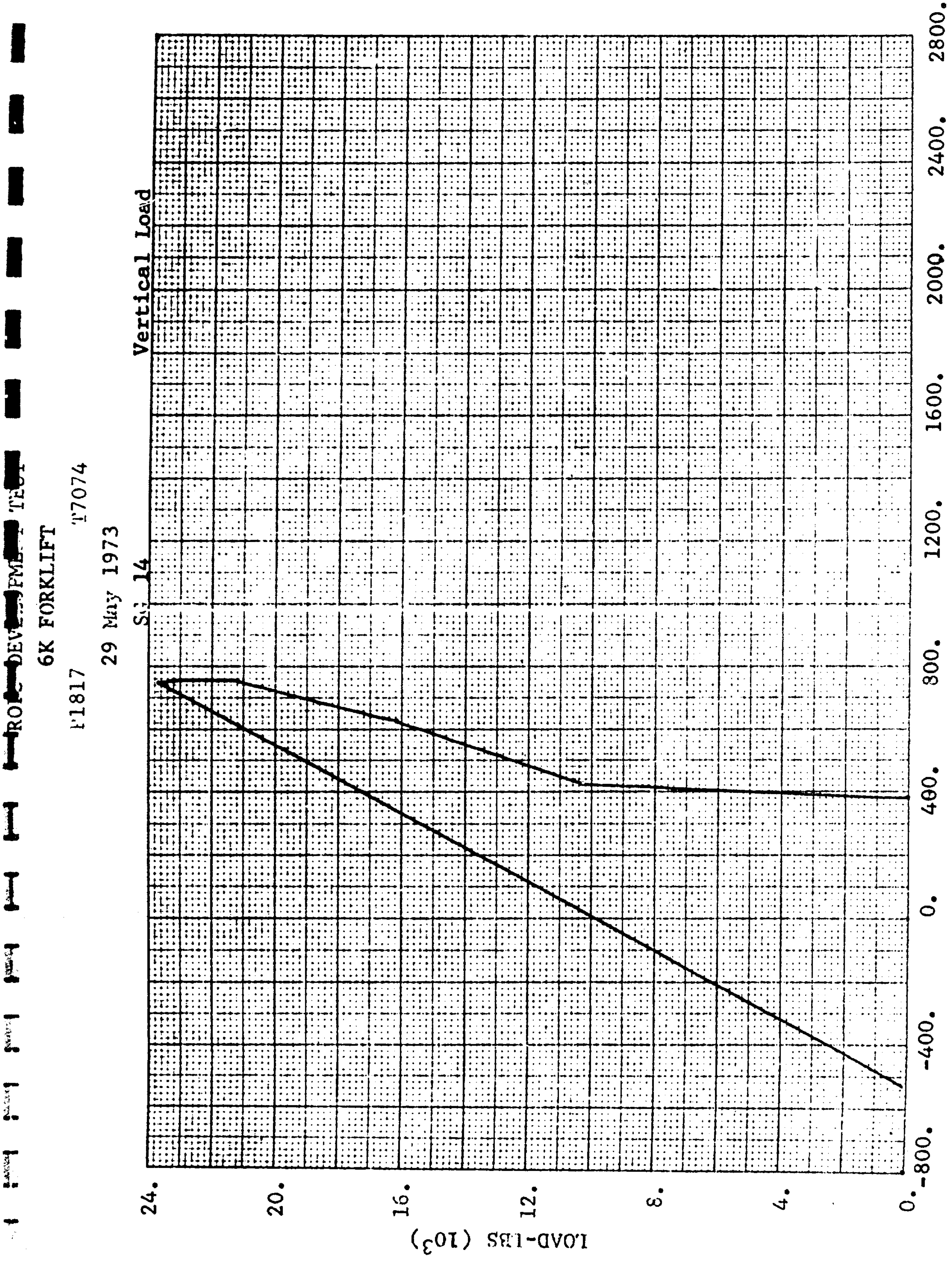

6K FORKLIFT
T7074
29 May 1973
S 10
Vertical Load
0.
500.
1000.
1500.
2000.
2500.
3000.
3500.
4000.
4500.
0.
4.
8.
12.
16.
20.

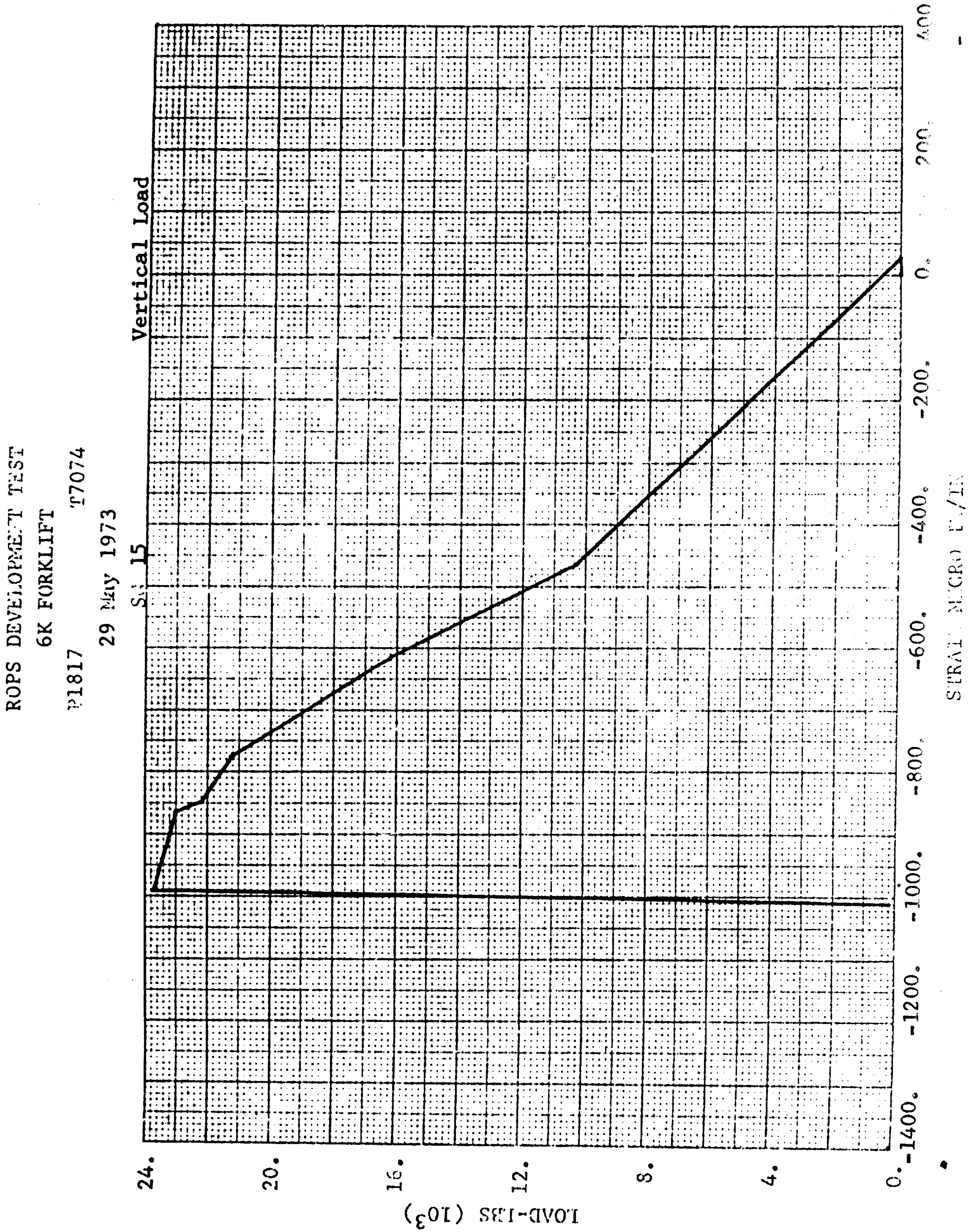

6K FORKLIFT
1817
T7074
29 May 1973
Vertical Load
24.
20.
12.
8.
4.
0.
-3020.
-3040.
-3060.
-3080.
-3100.
-3120.
-3140.
-3160.
-3180.
-3200.


6K FORKLIFT
29 May 1973
Vertical Load
800.
400.
0.
-400.
-800.
-1200.
-1600.
-2000.
-2400.
-2800.
24.
20.
12.
8.
4.
0.

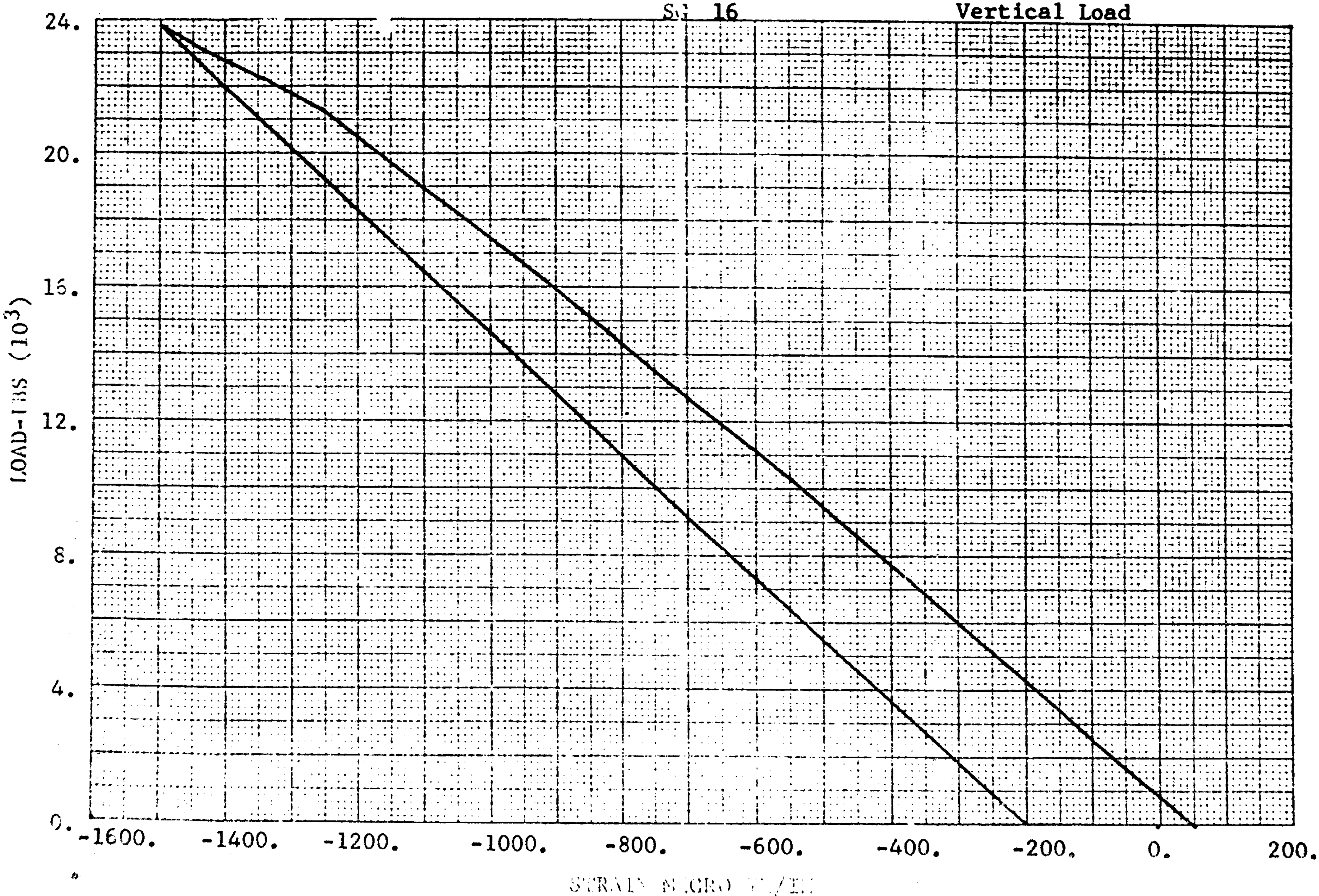
ROPS DEVELO'ME'T TEST
6K FORKLIFT
P1817 T7074
29 May 1973
S. 13

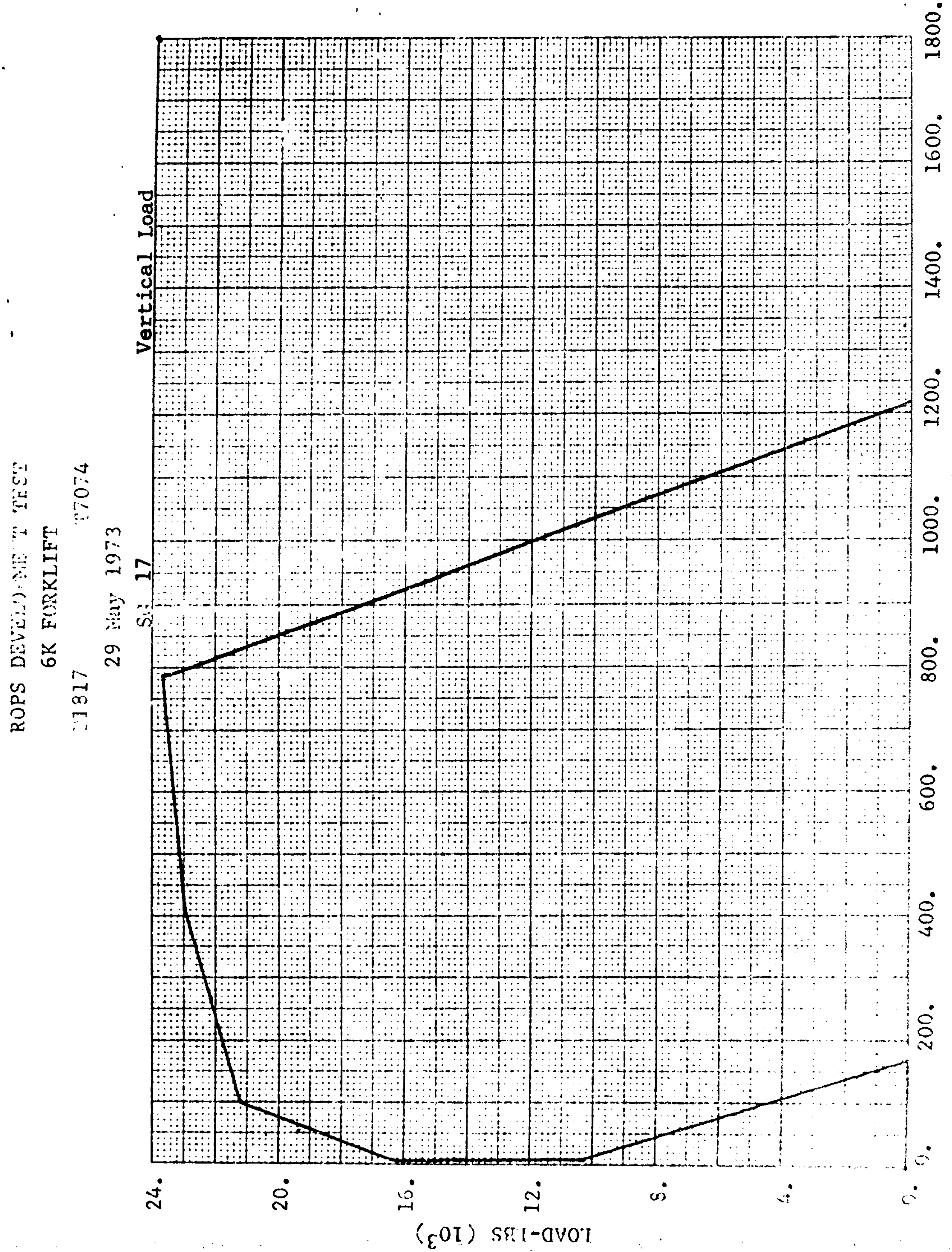



6K FORKLIFT
F1817
T7074
29 May 1973
Vertical Load
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
-800.
-400.
0.
400.
800.
1200.
1600.
2000.
2400.
2800.


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 15
Vertical Load
LOAD-LBS (10³)
24.
20.
16.
12.
8.
4.
0.
-1400.
-1200.
-1000.
-800.
-600.
-400.
-200.
0.
200.
400.

ROLS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 16 Vertical Load




ROPS DEVELOPMENT TEST
6K FORKLIFT
1317 T7074
29 May 1973
SS 17
Vertical Load
LOAD-LBS (10³)
24.
20.
16.
12.
8.
4.
0.
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.

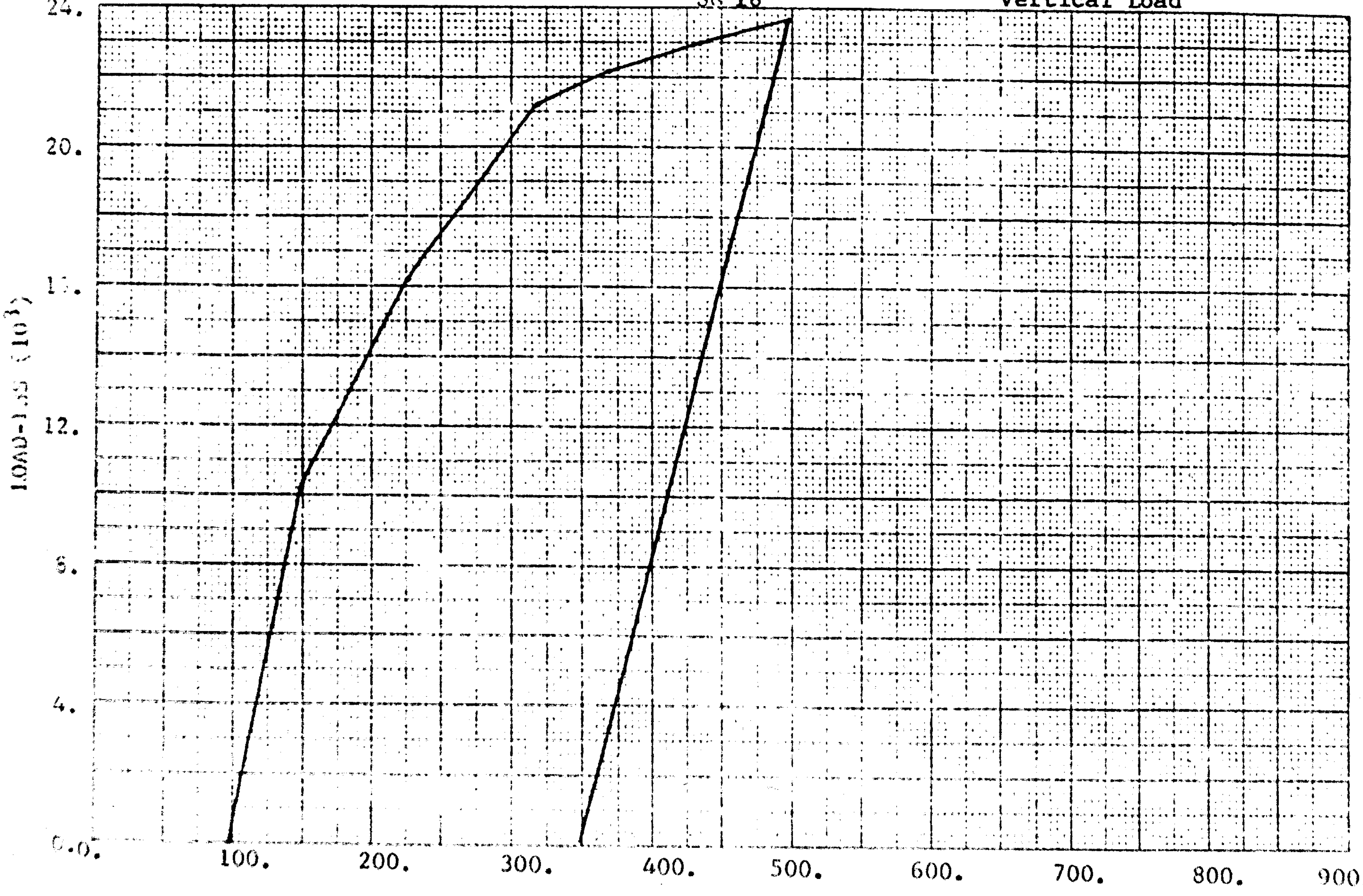
ROPS DEVELOPMENT TEST

6K FORKLIFT

F1817 T7074

29 May 1973

SG 18 Vertical Load



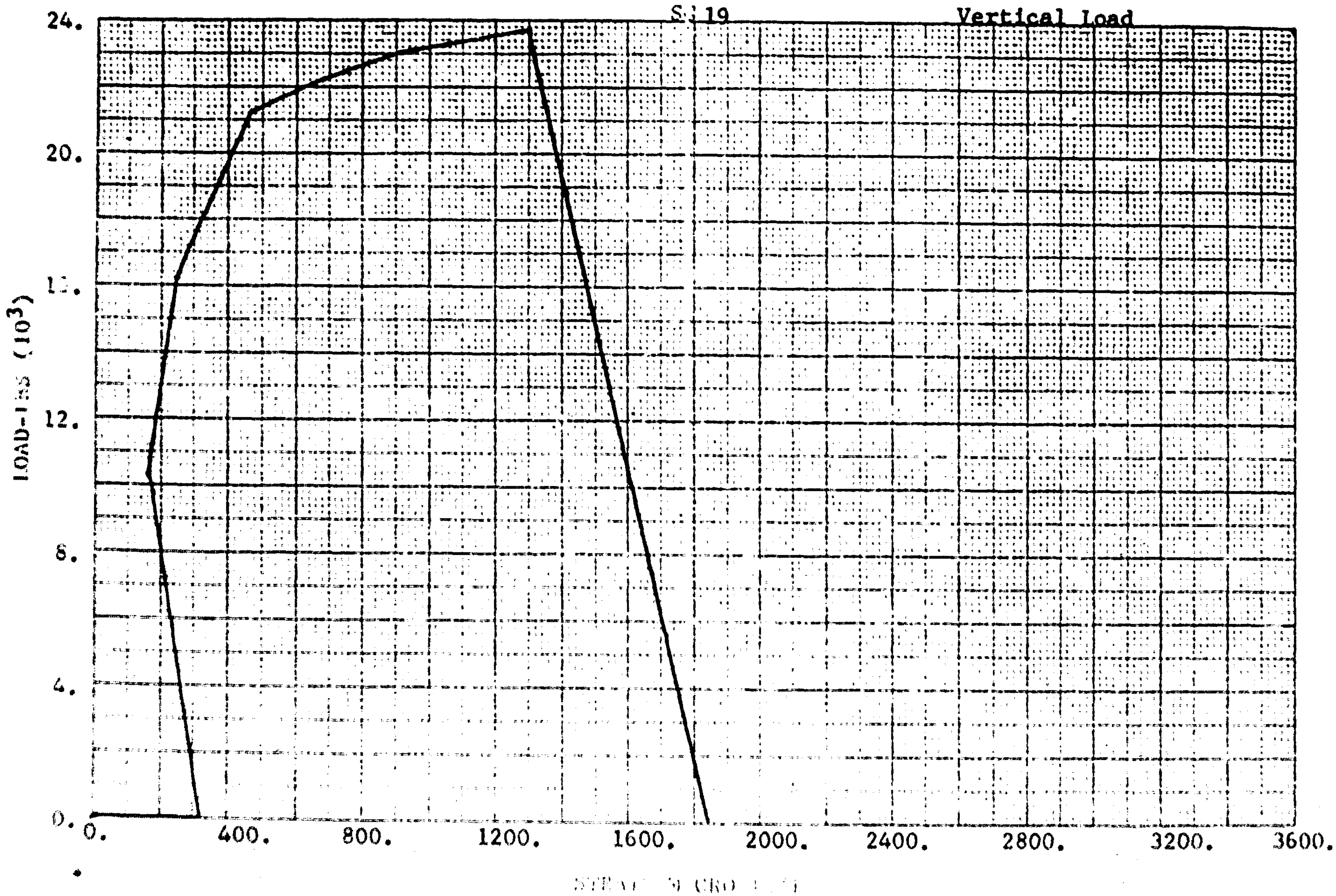
ROPS DEVELOPMENT TEST

6K FORKLIFT

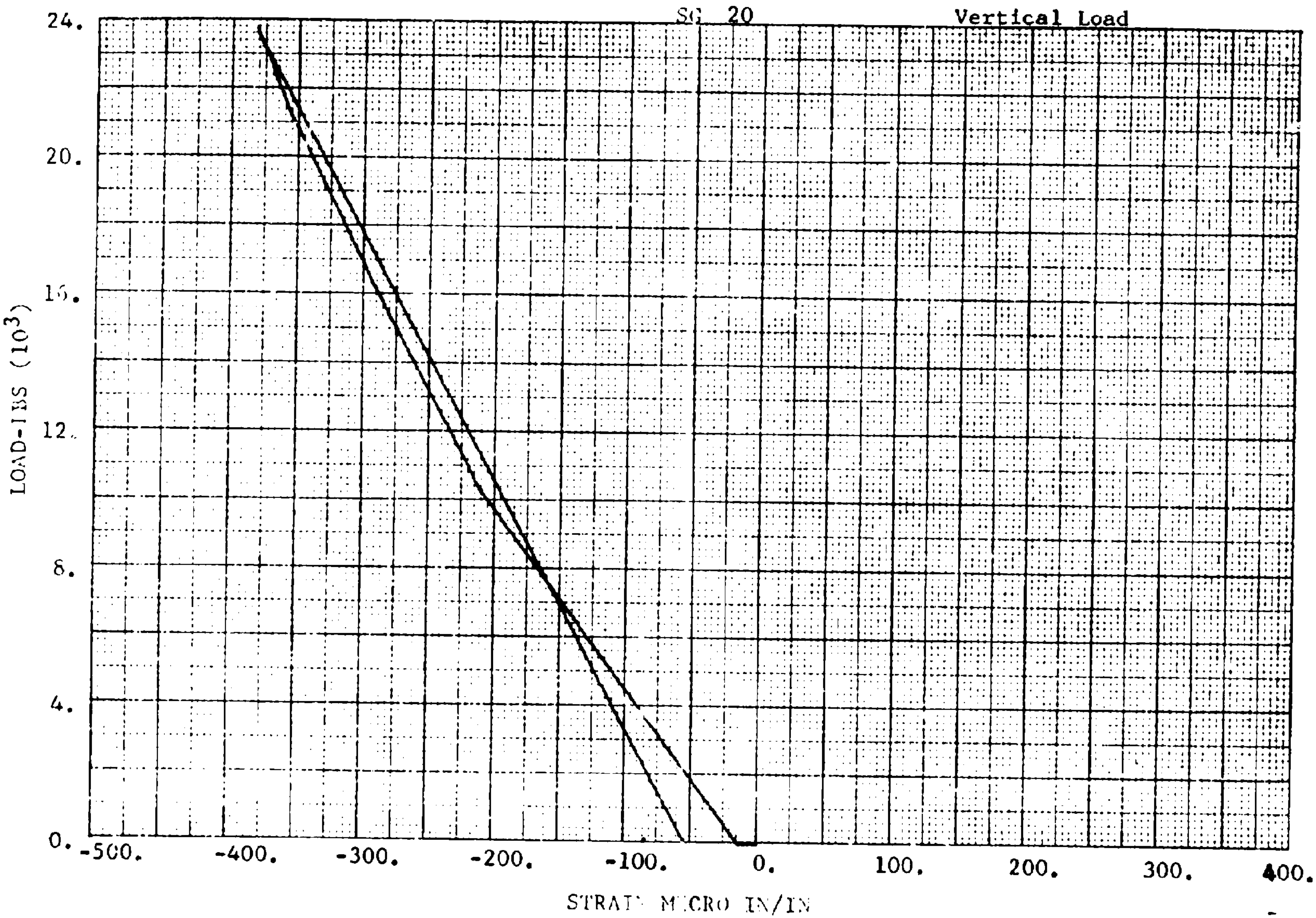
F1817 T7074

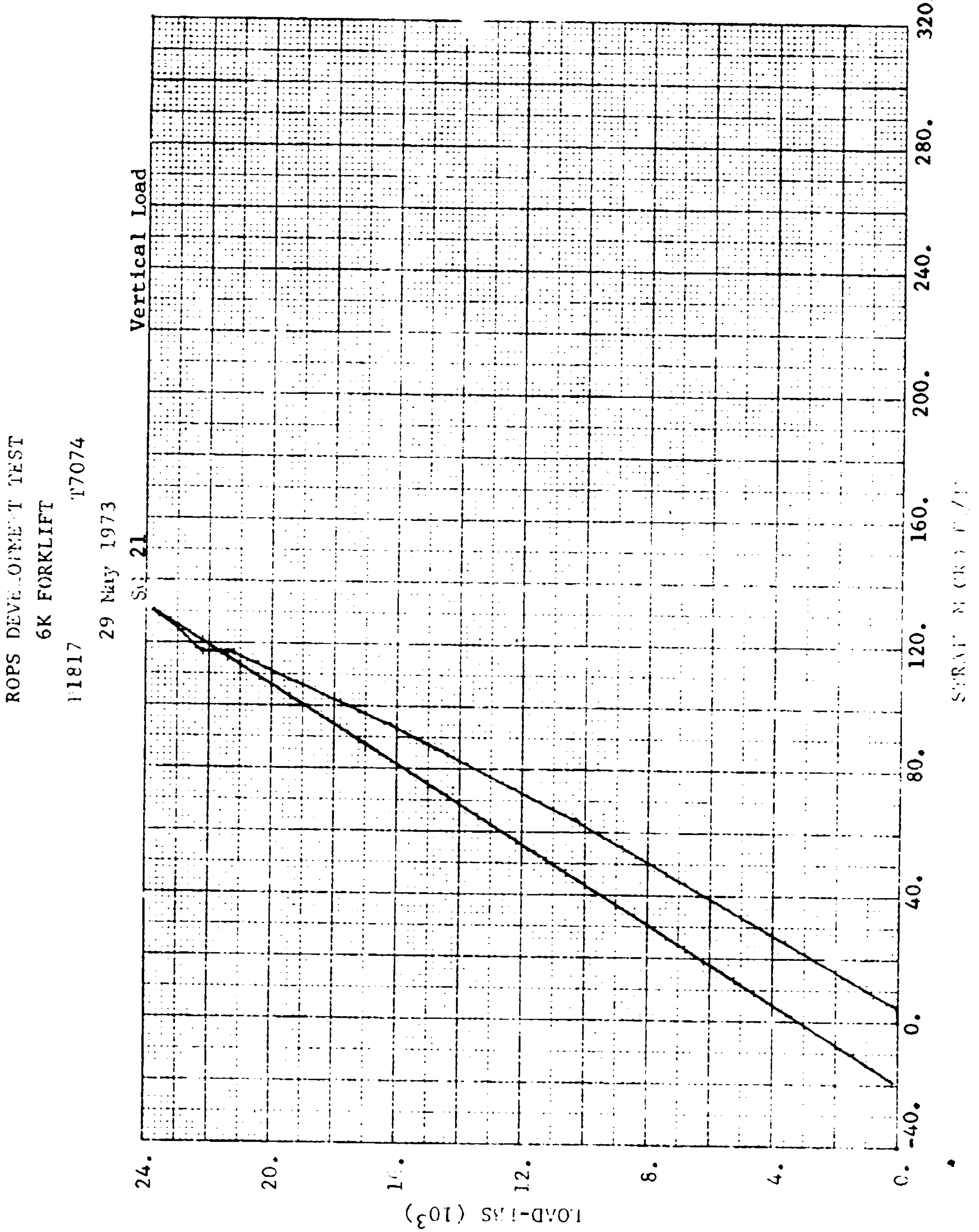
29 May 1973

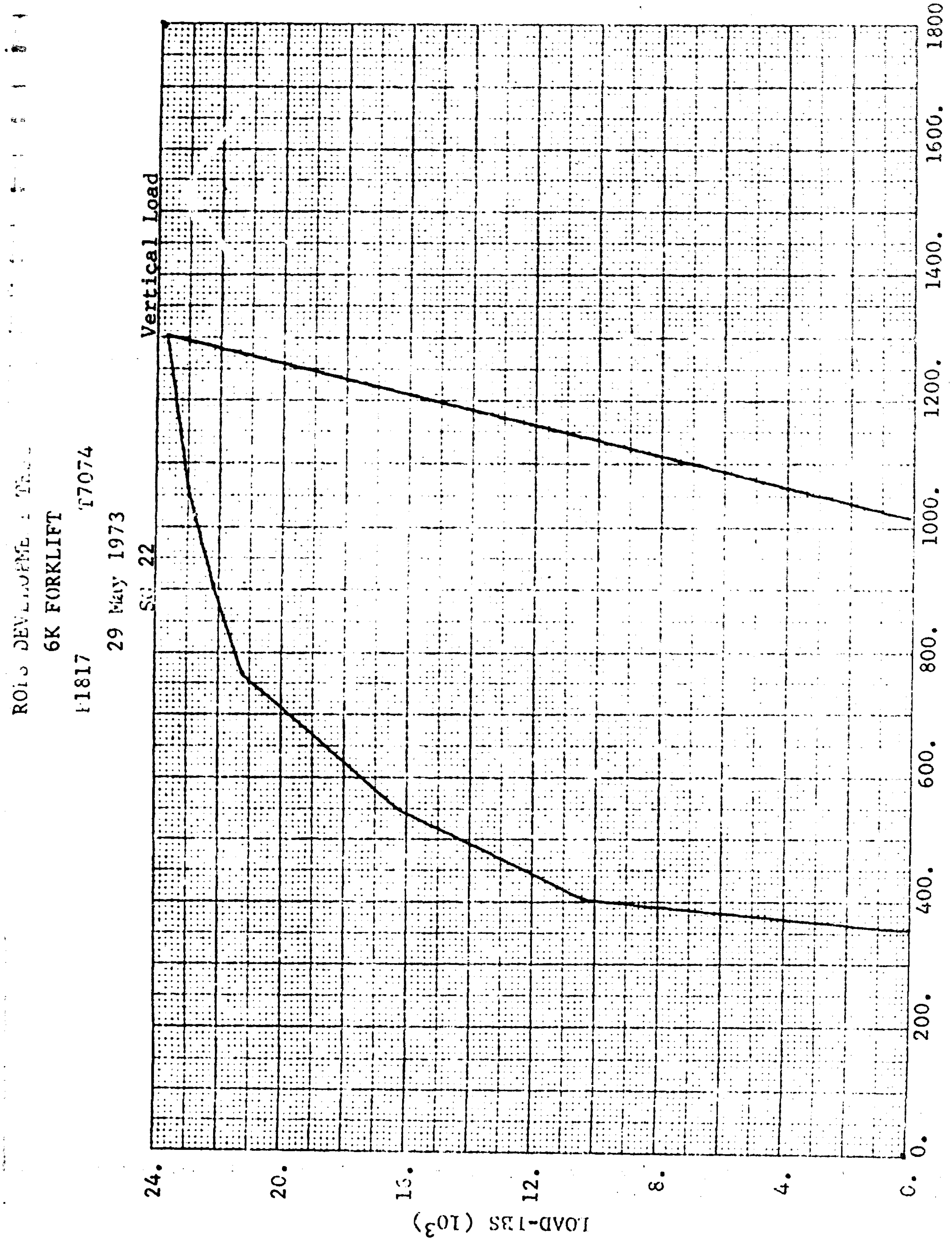
S 19



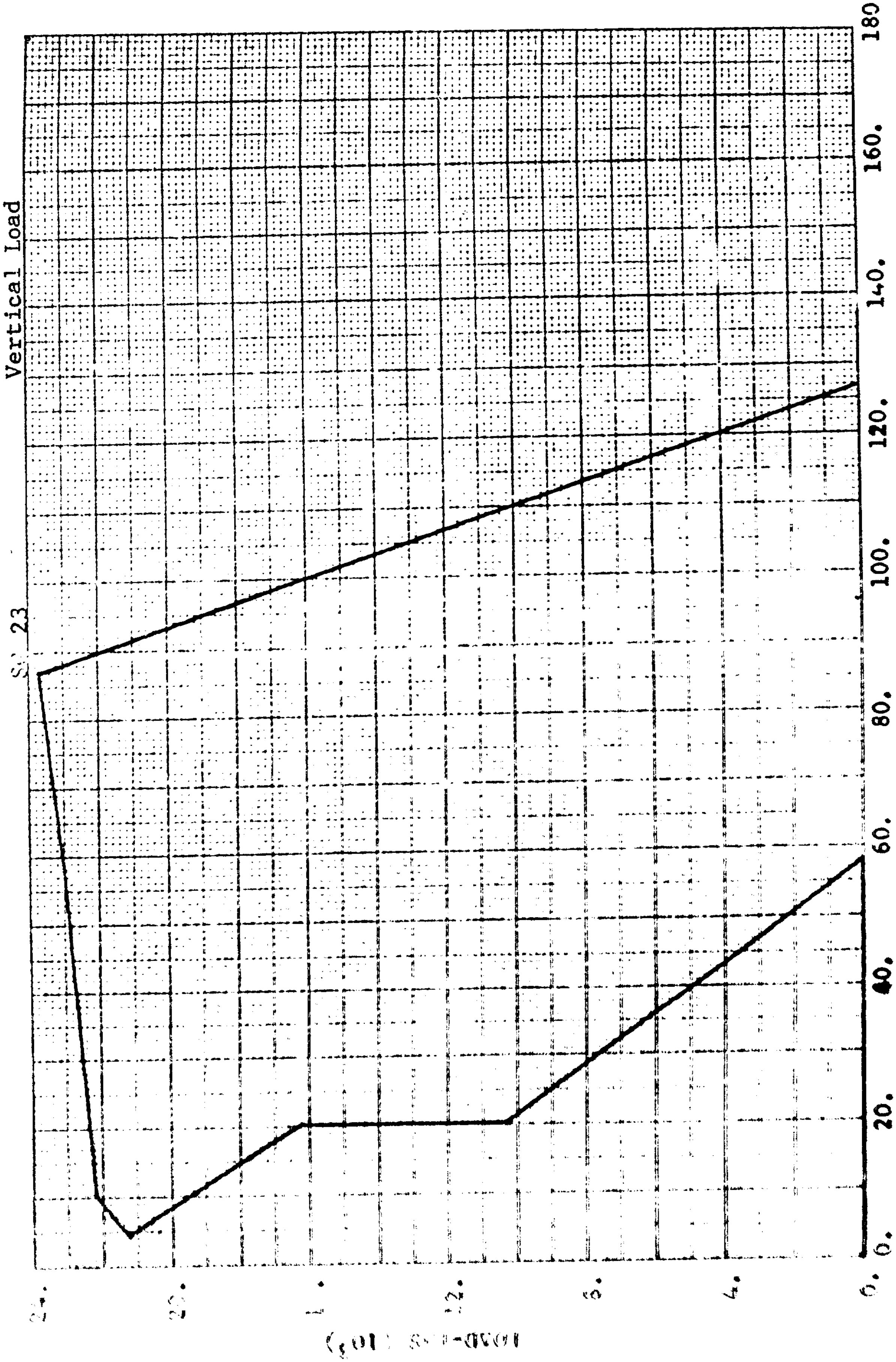
ROF. DEVL..TME . TE.
6K FORKLIFT
P1817 T7074
29 May 1973

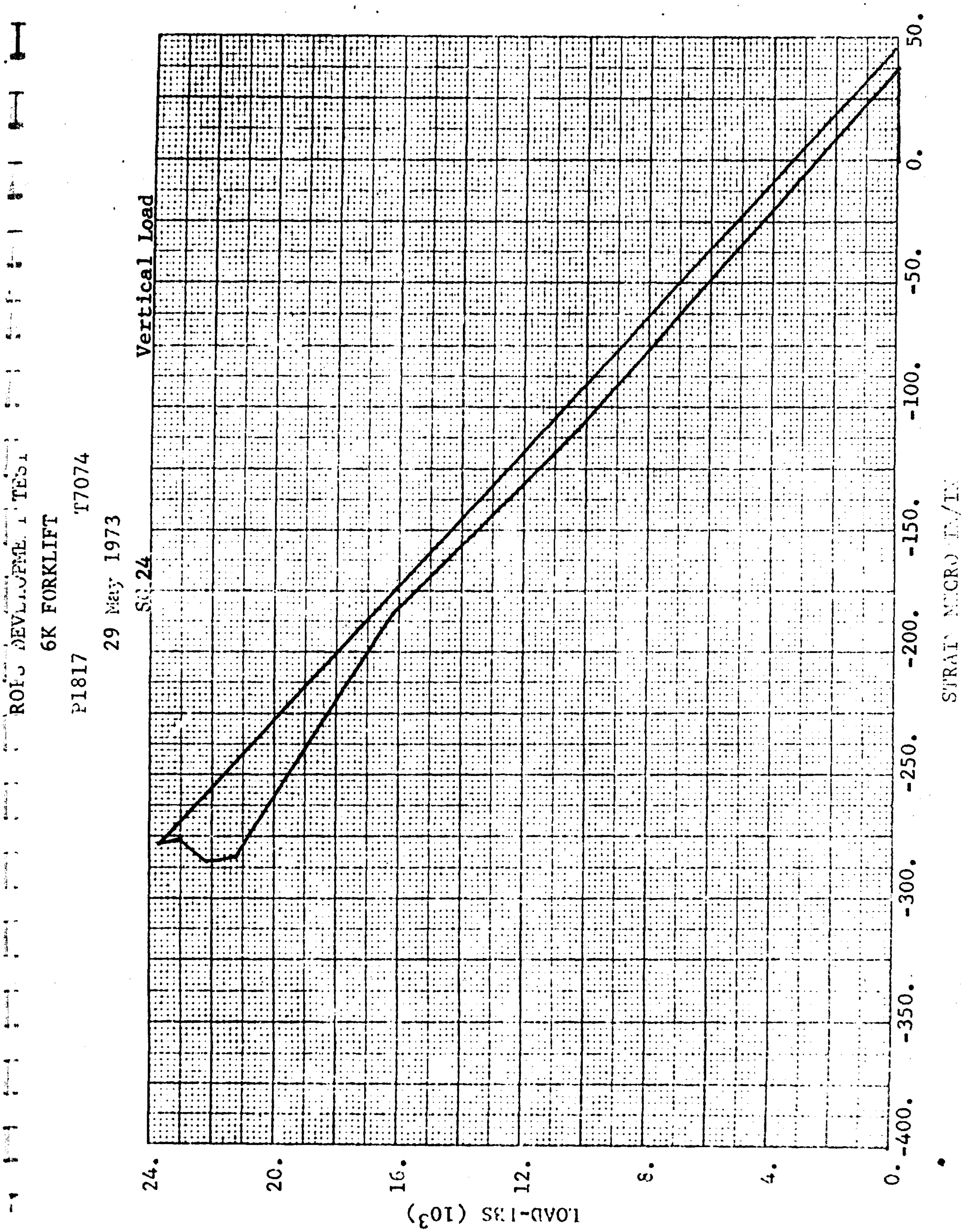



ROPS DEVELOPMENT TEST
6K FORKLIFT
T7074
29 May 1973
Vertical Load
320.
280.
240.
200.
160.
120.
80.
40.
0.
-40.
24.
20.
12.
8.
4.
LOAD-LBS (10^3)

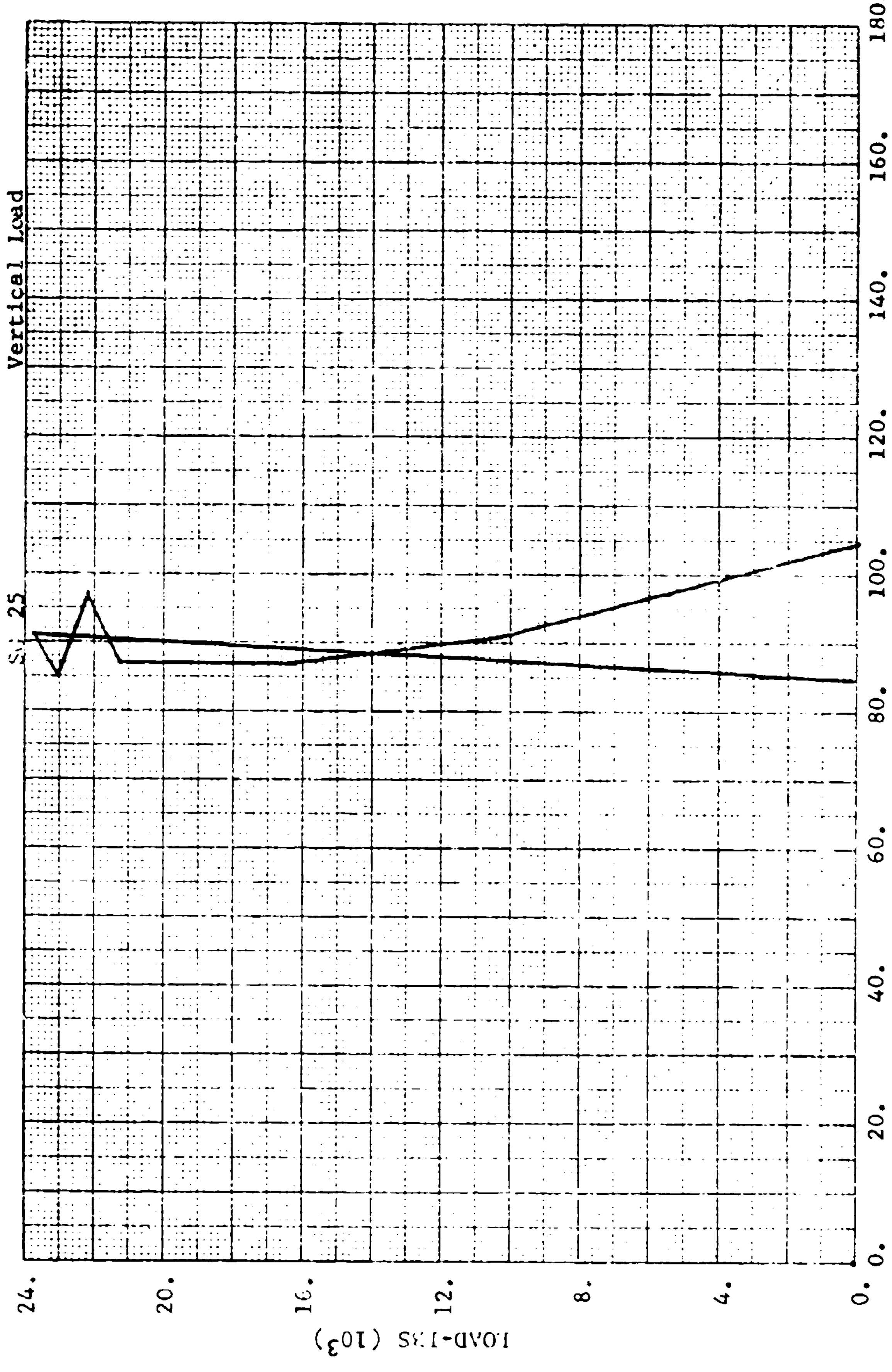

6K FORKLIFT
T7074
29 May 1973
Vertical Load
24.
20.
12.
8.
4.
0.
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.

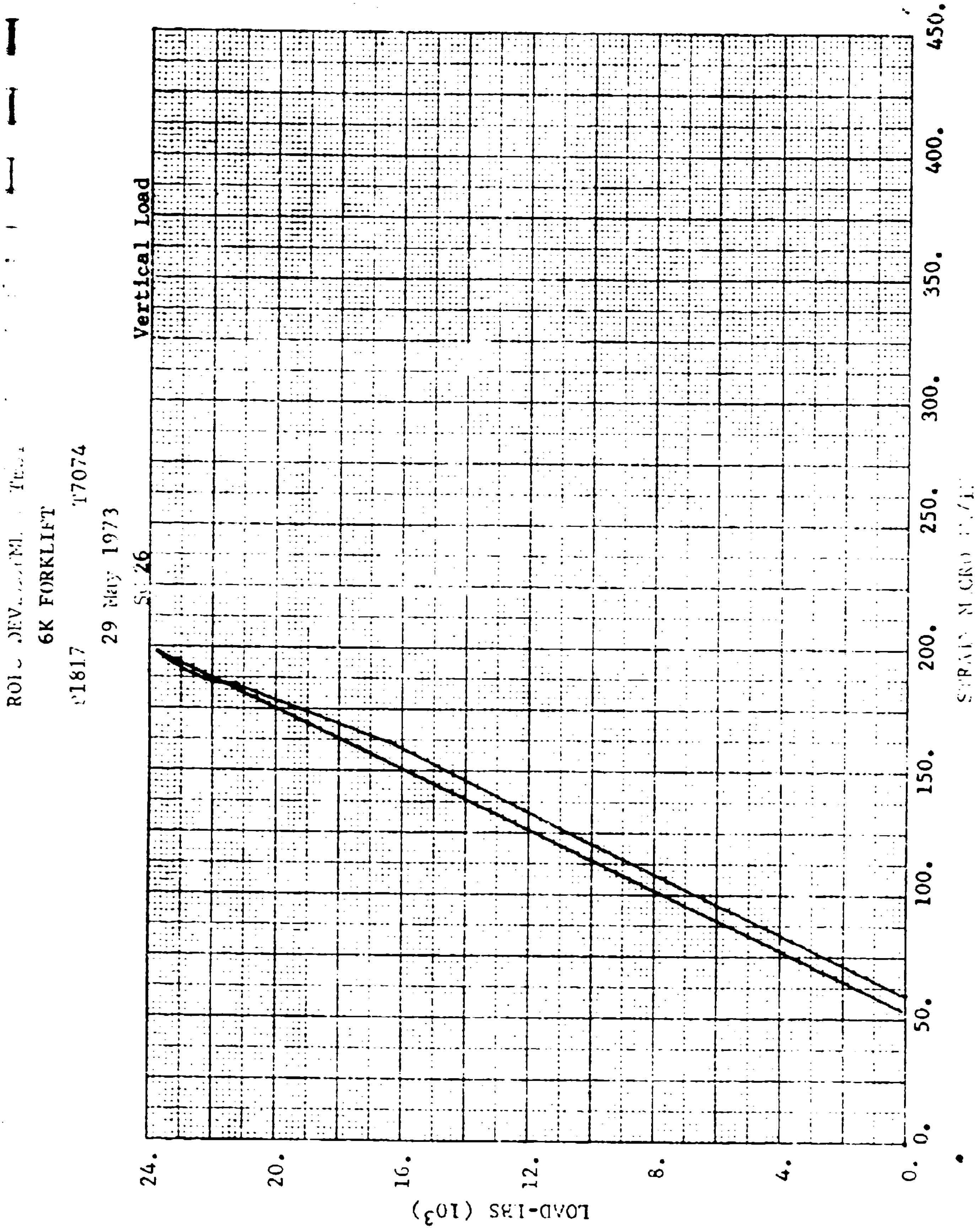
ROPS DEVELOPMENT TEST
6K FORKLIFT
1817 E7074
29 May 1973

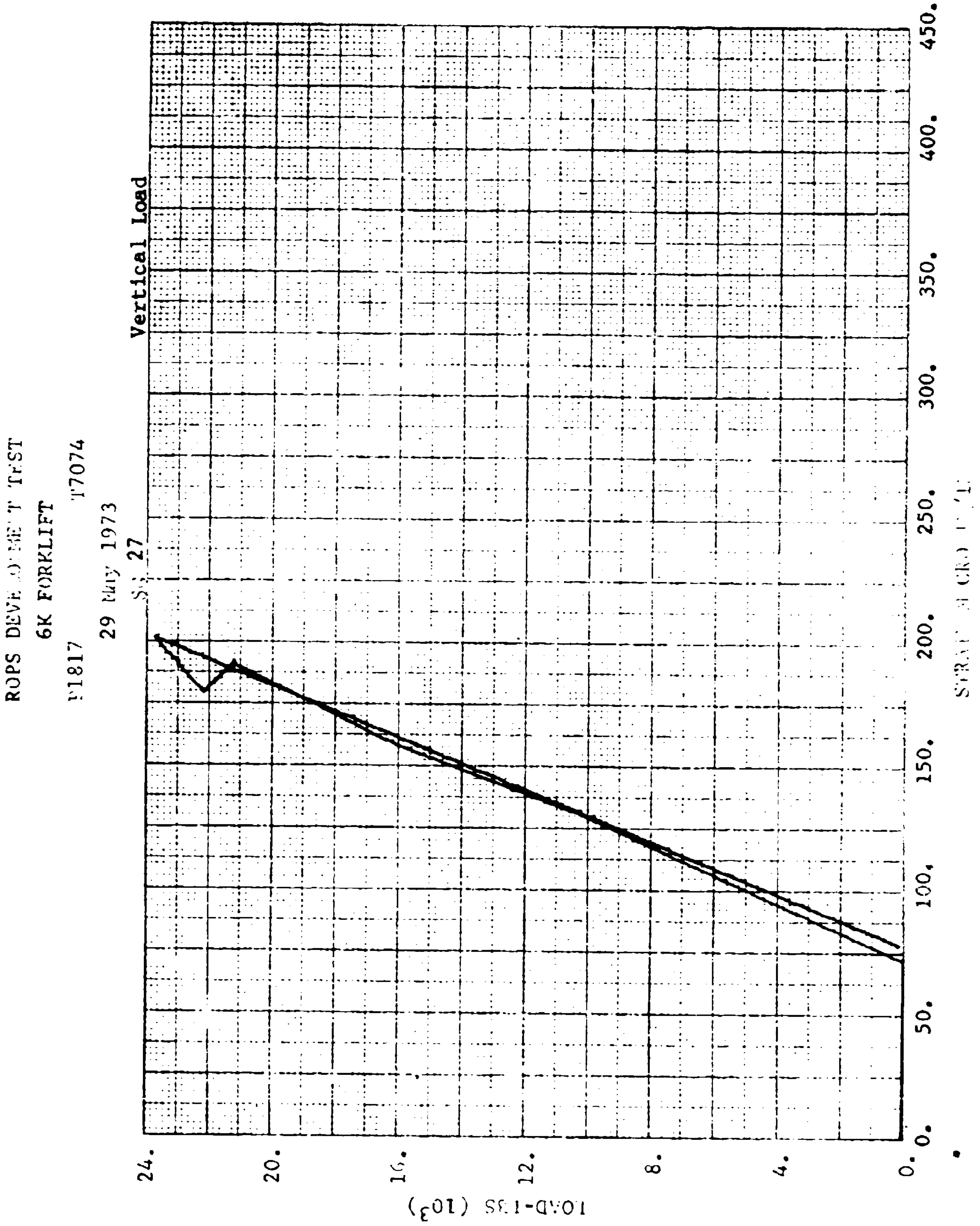


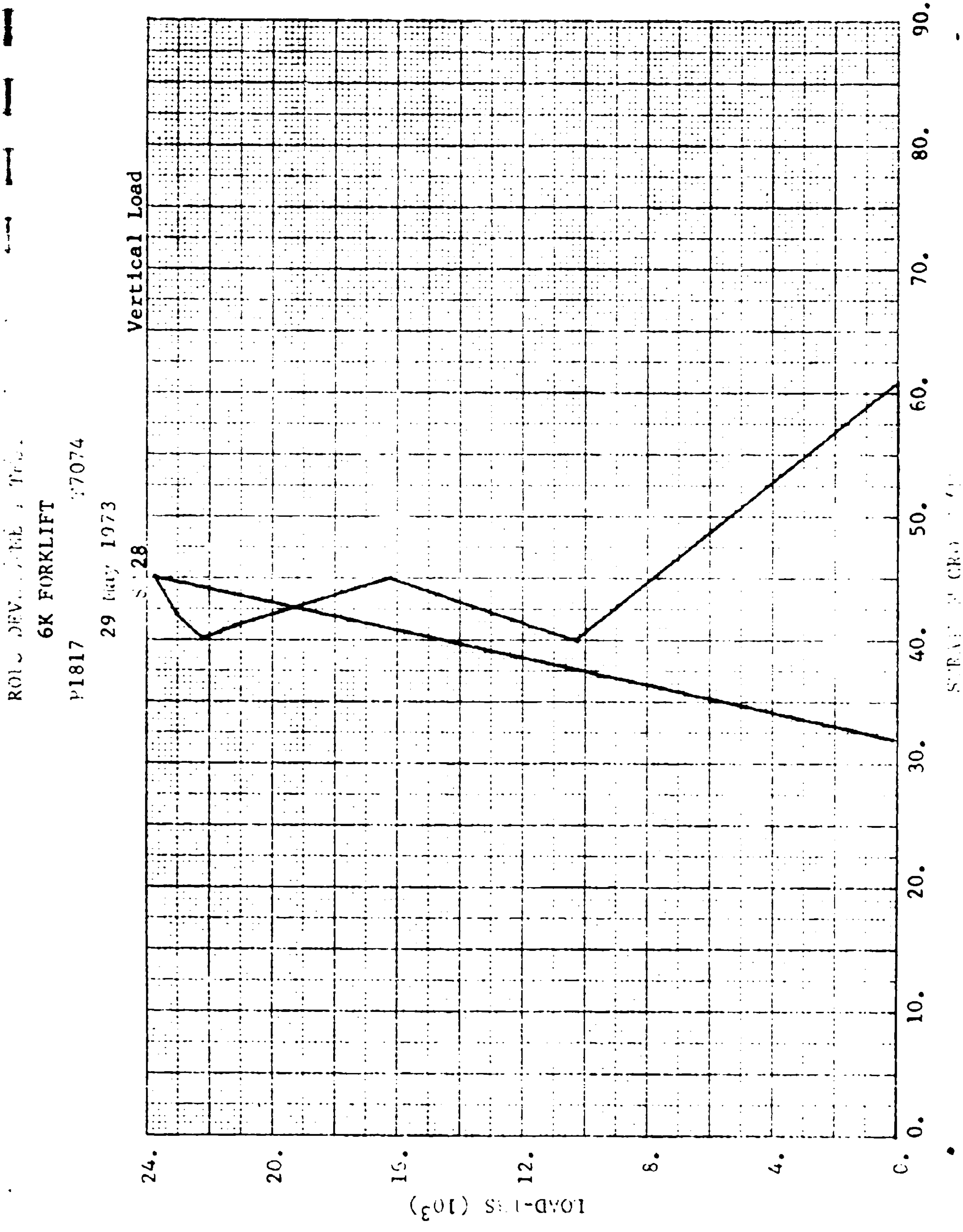

ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817
T7074
29 May 1973
SG 24
Vertical Load
50.
0.
-50.
-100.
-150.
-200.
-250.
-300.
-350.
-400.
STRAIN MICRO IN/IN
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)

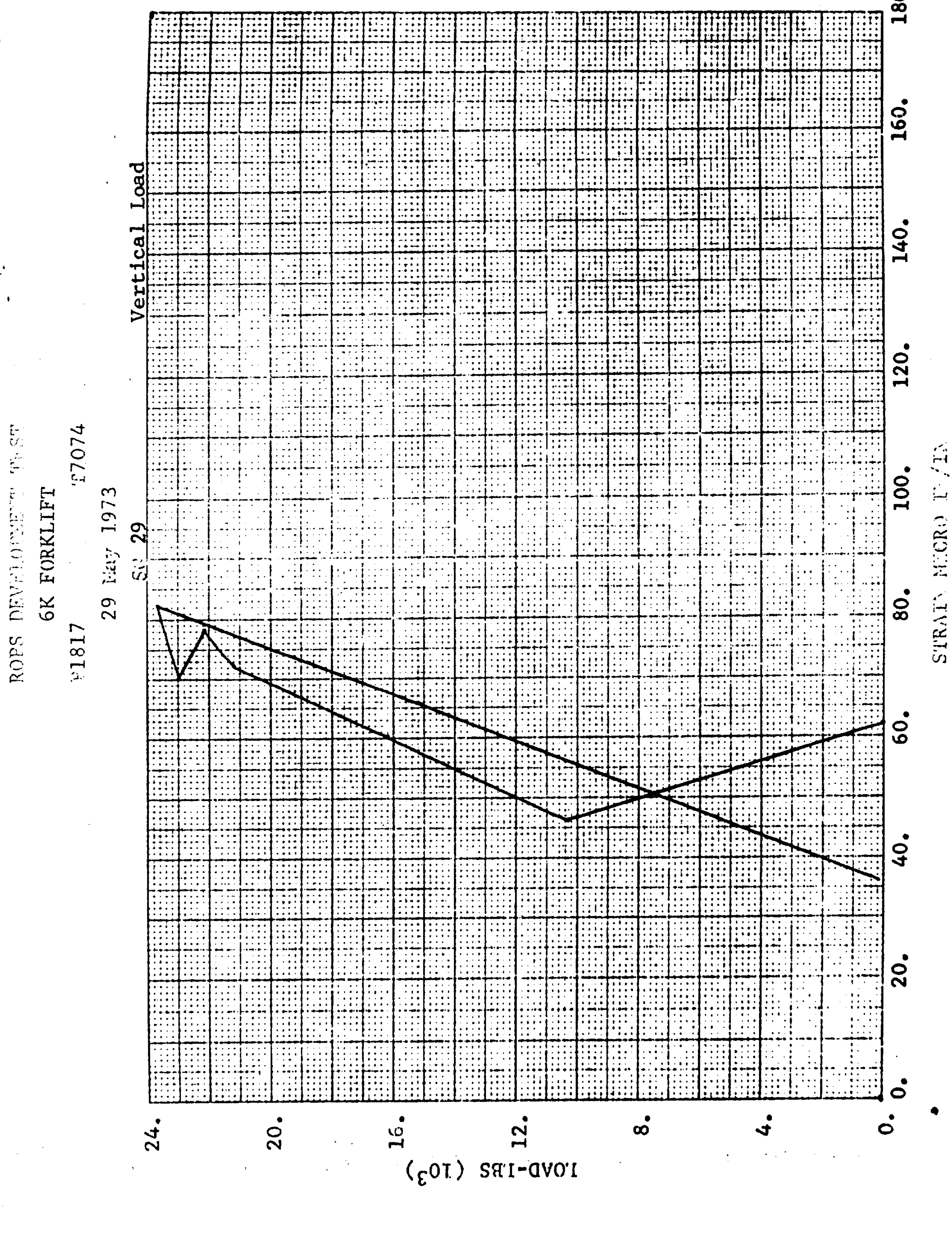
ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973

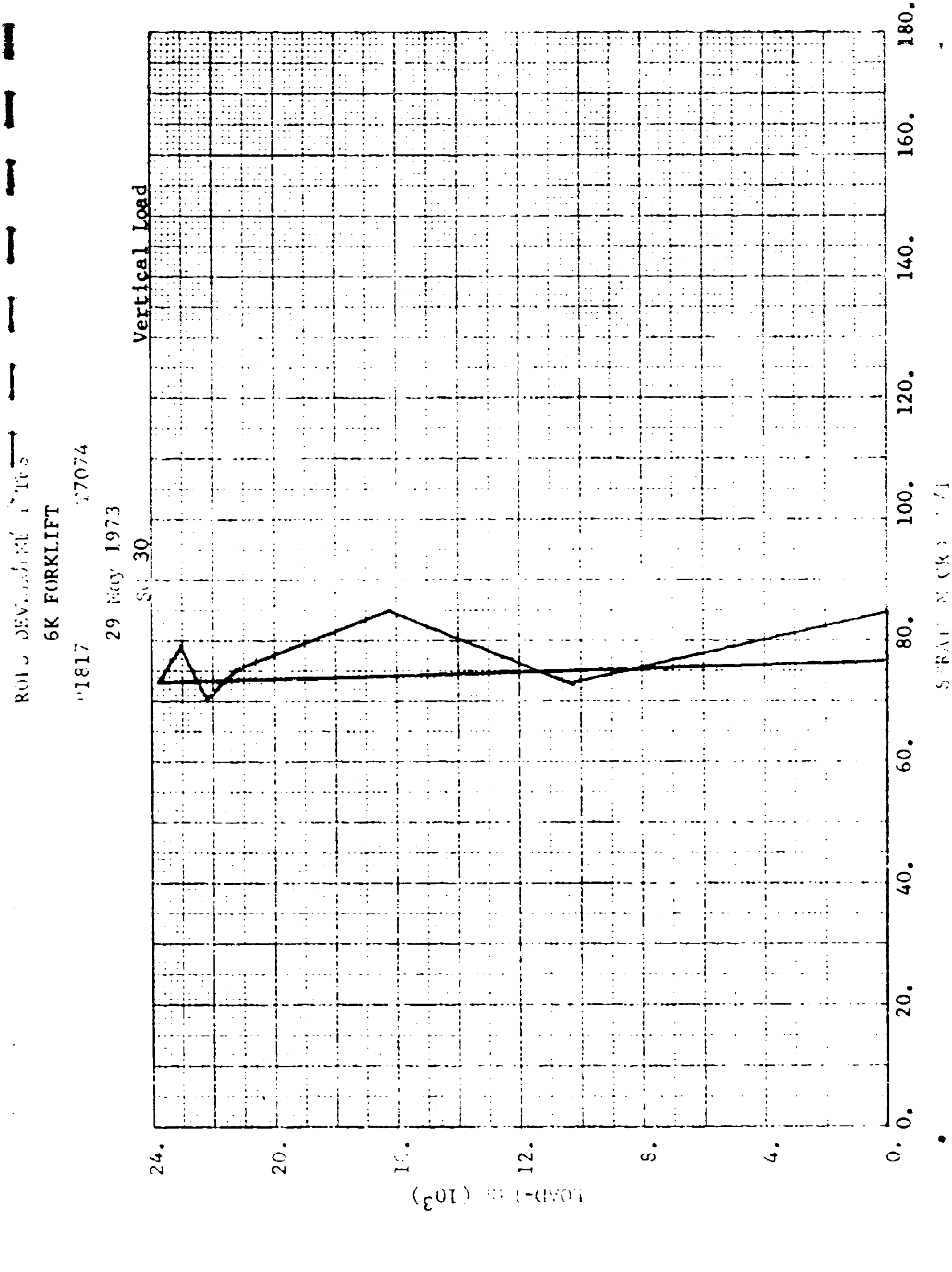


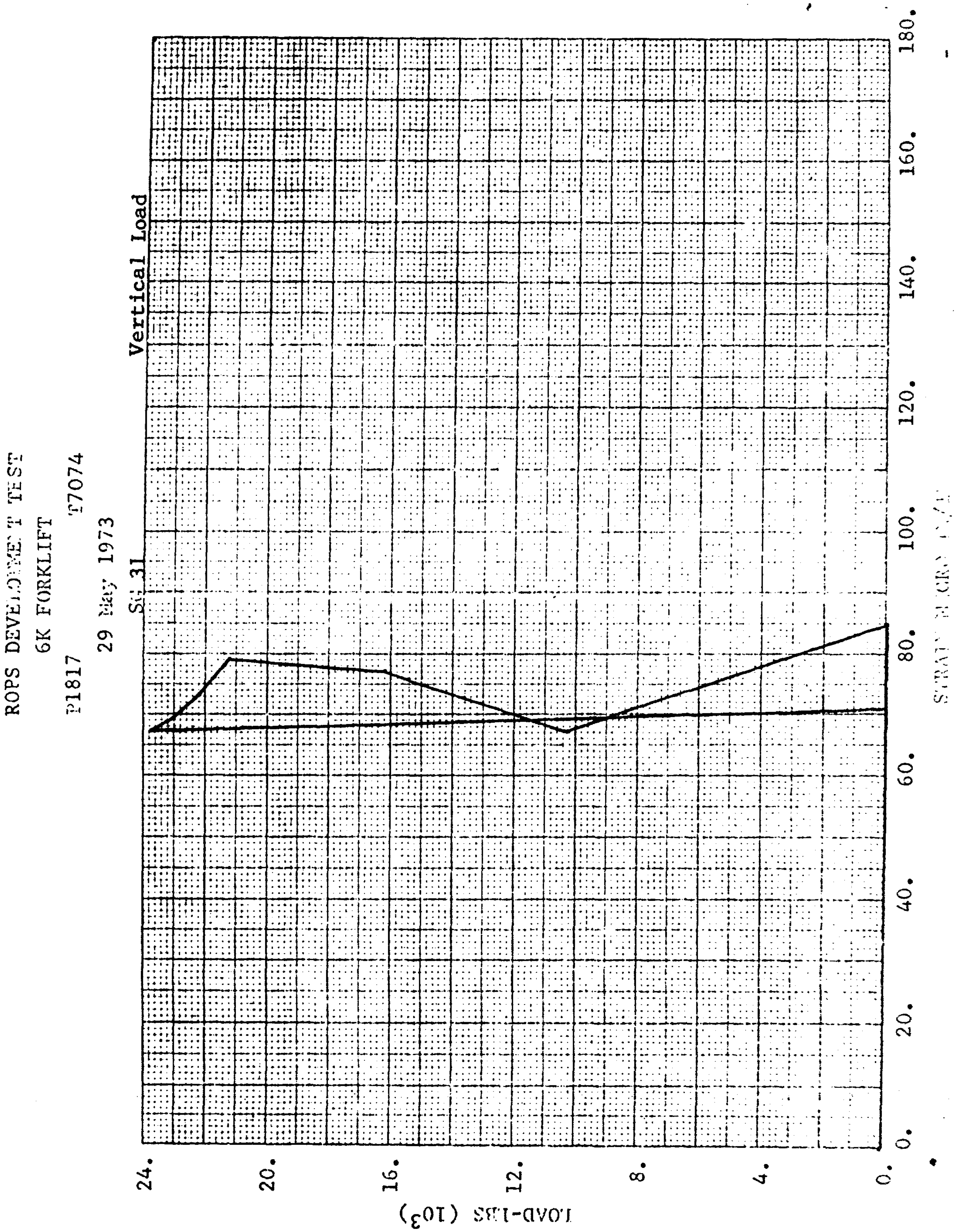

6K FORKLIFT
T7074
29 May 1973
Vertical Load
0.
50.
100.
150.
200.
250.
300.
350.
400.
450.
0.
4.
8.
12.
16.
20.
24.
LOAD-LBS (10^3)

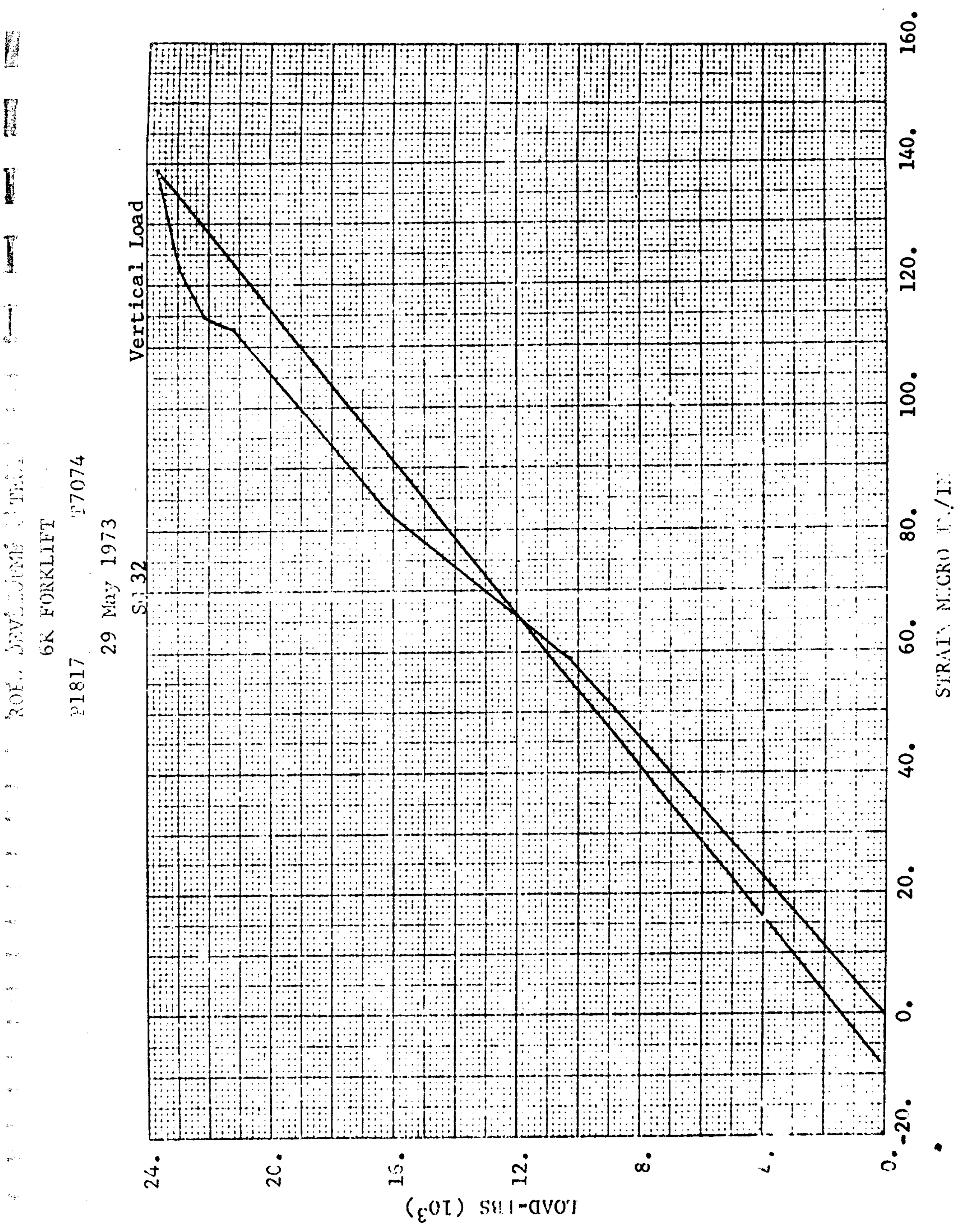

6K FORKLIFT
T7074
29 May 1973
Vertical Load
24.
20.
12.
8.
4.
0.
0.
50.
100.
150.
200.
250.
300.
350.
400.
450.


6K FORKLIFT
P1817
Vertical Load
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
24.
20.
12.
8.
4.


6K FORKLIFT
29 May 1973
Vertical Load
LOAD-LBS (10^3)
0.
4.
8.
12.
16.
20.
24.
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.


6K FORKLIFT
1817
7074
29 May 1973
30
Vertical Load
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
24.
20.
12.
4.
0.
(10³)


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
Vertical Load
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)

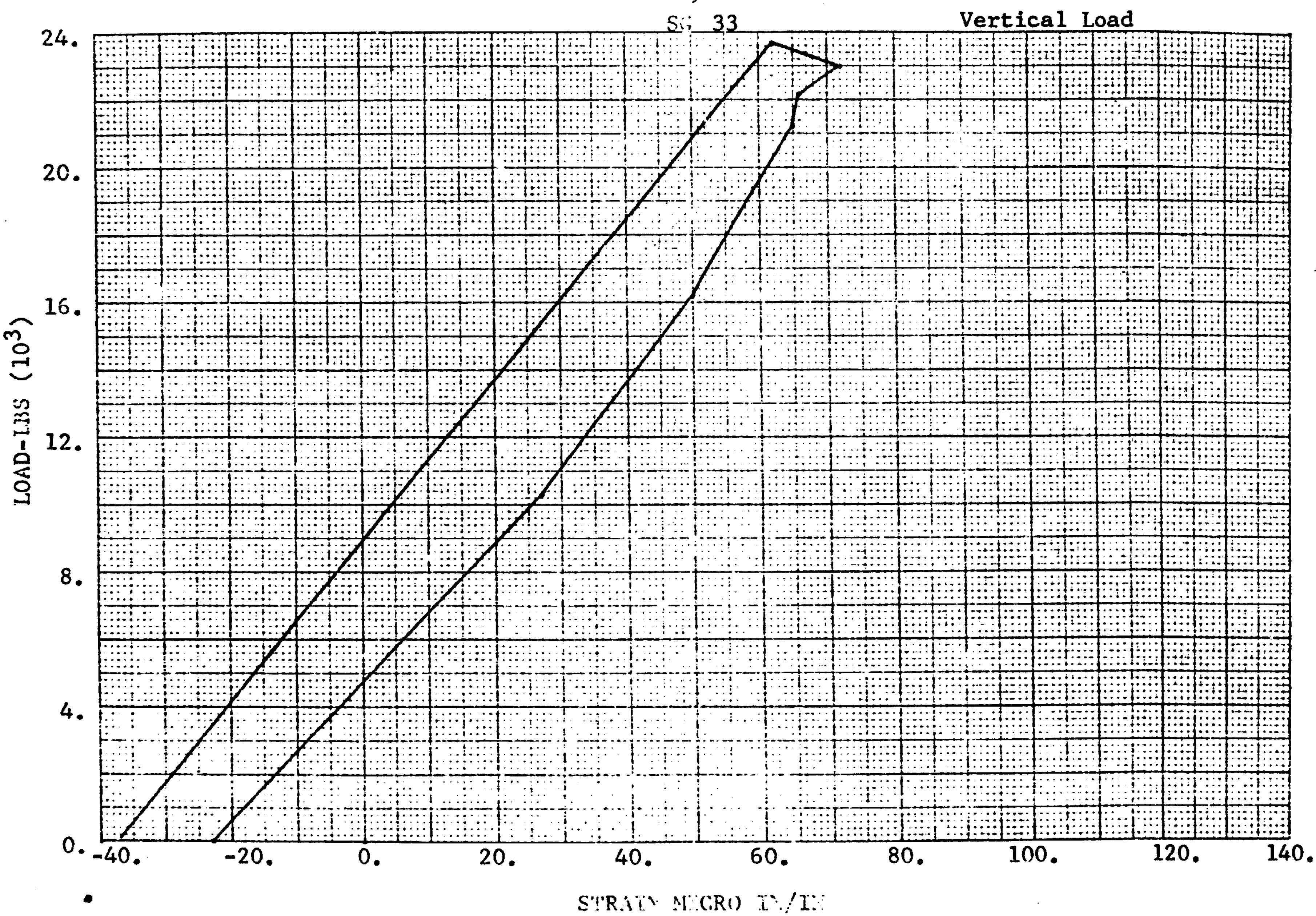

Vertical Load
6K FORKLIFT
P1817 T7074
29 May 1973
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.

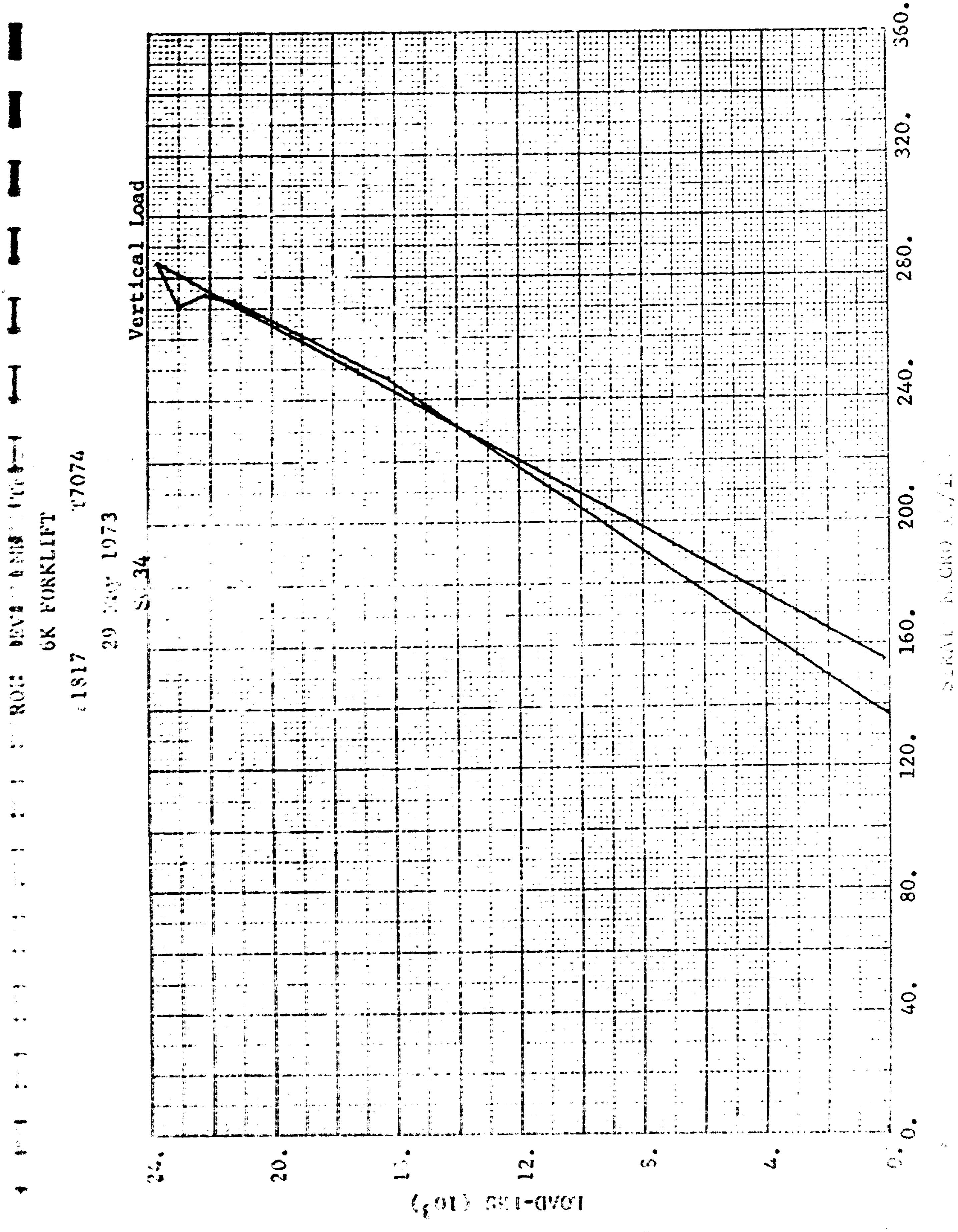
ROPS DEVELOPMENT TEST

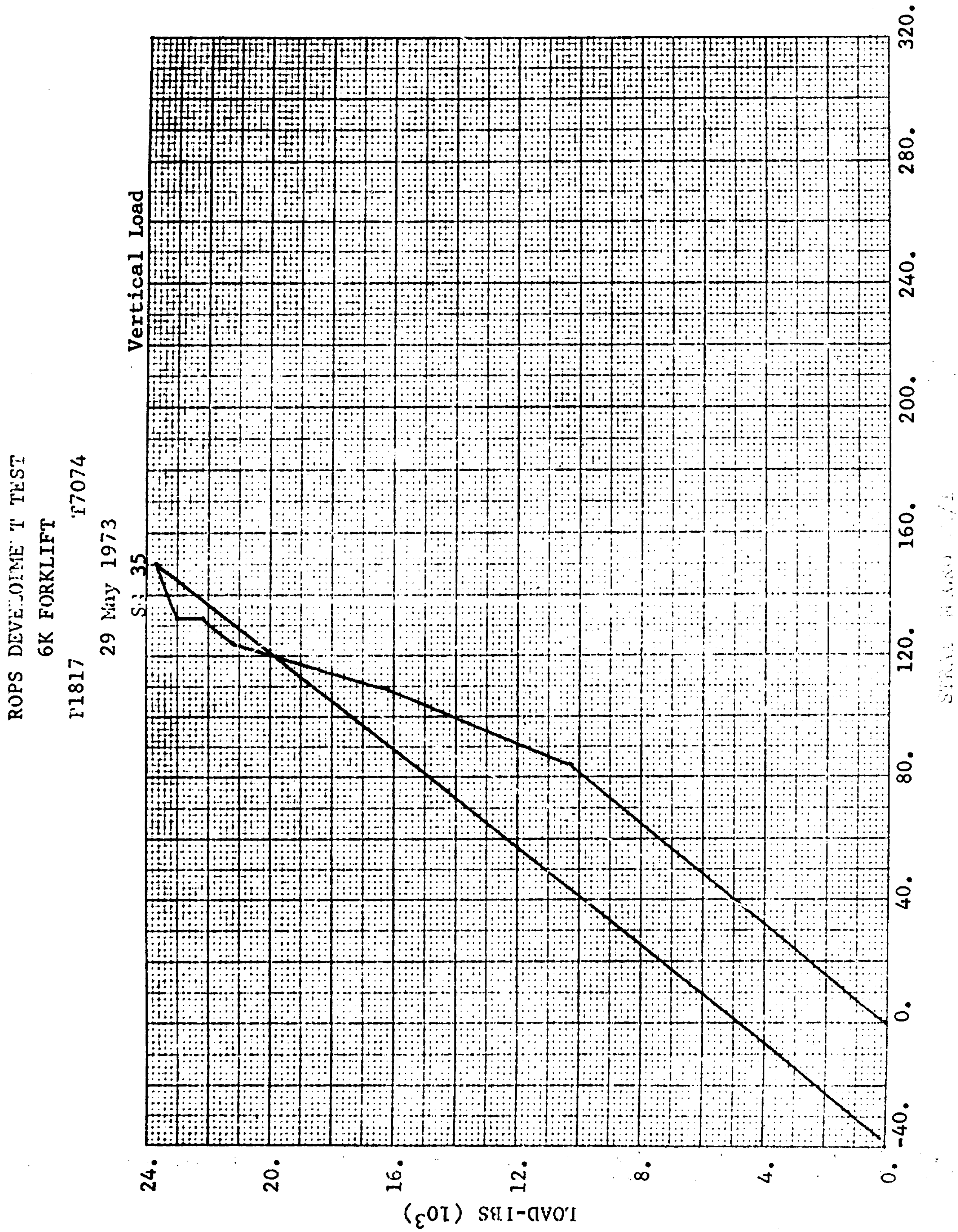
6K FORKLIFT

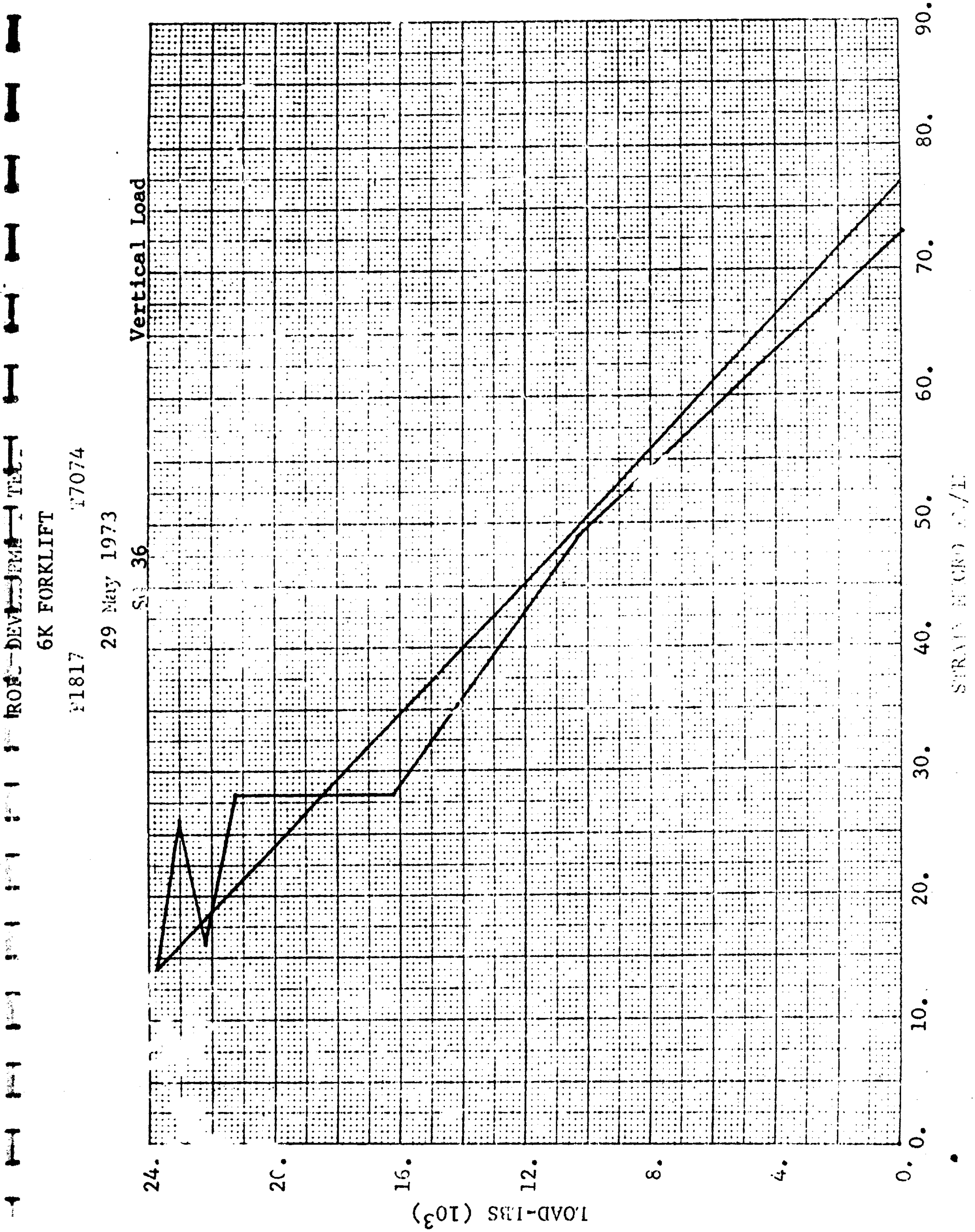
P1817 T7074

29 May 1973

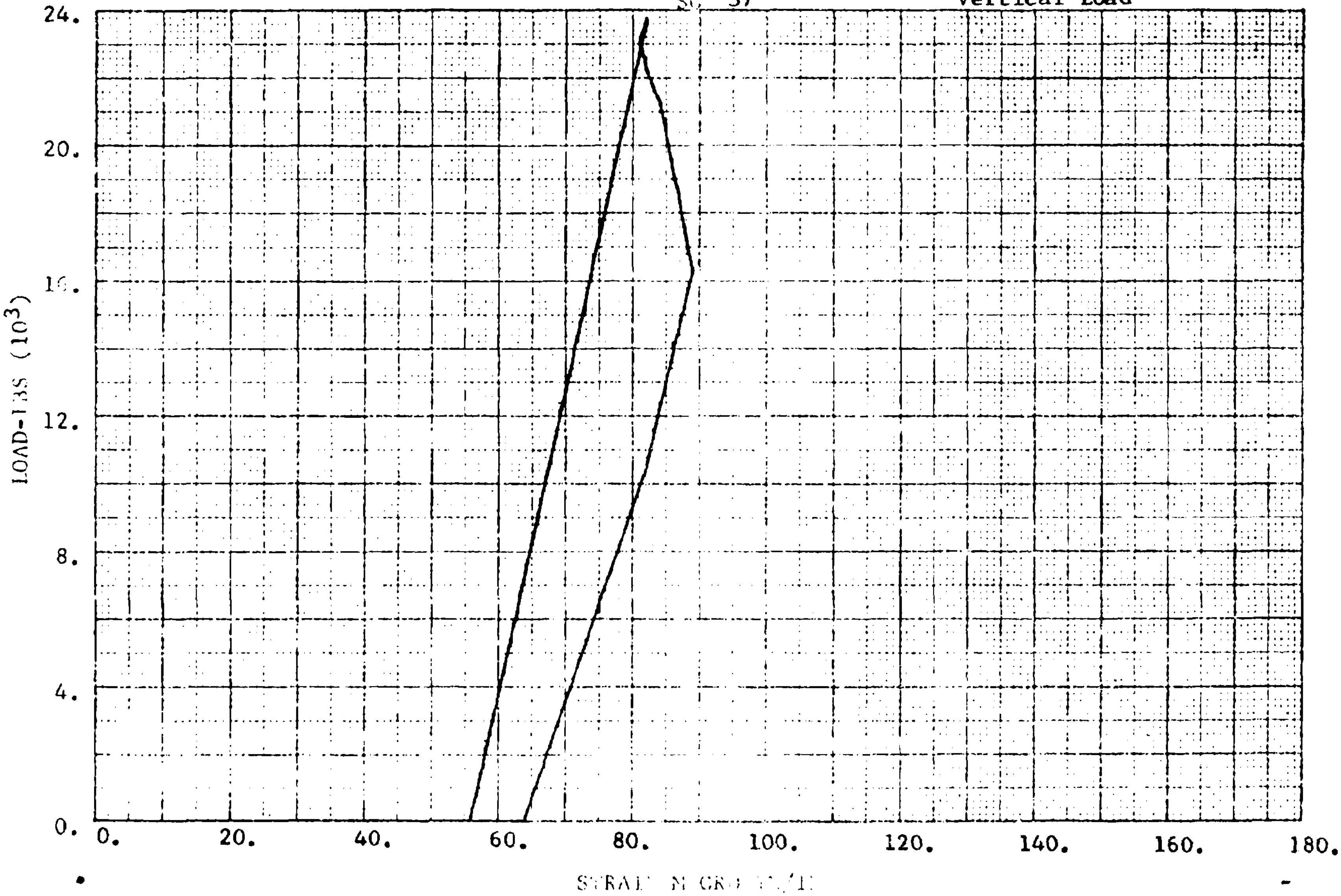


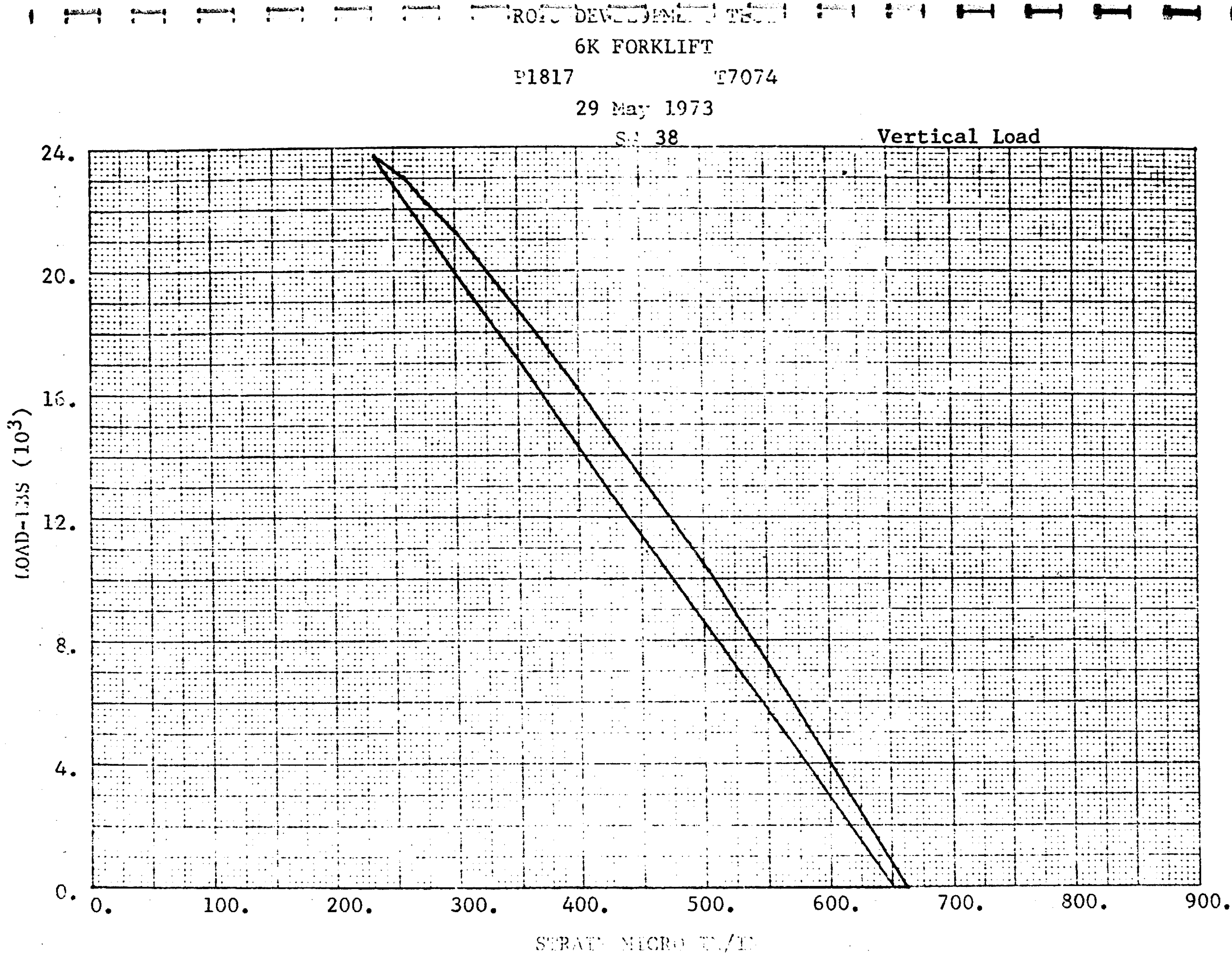

6K FORKLIFT
T7074
1817
29 May 1973
Vertical Load
LOAD-LBS (10³)
24.
20.
12.
8.
4.
0.
0.
40.
80.
120.
160.
200.
240.
280.
320.
360.

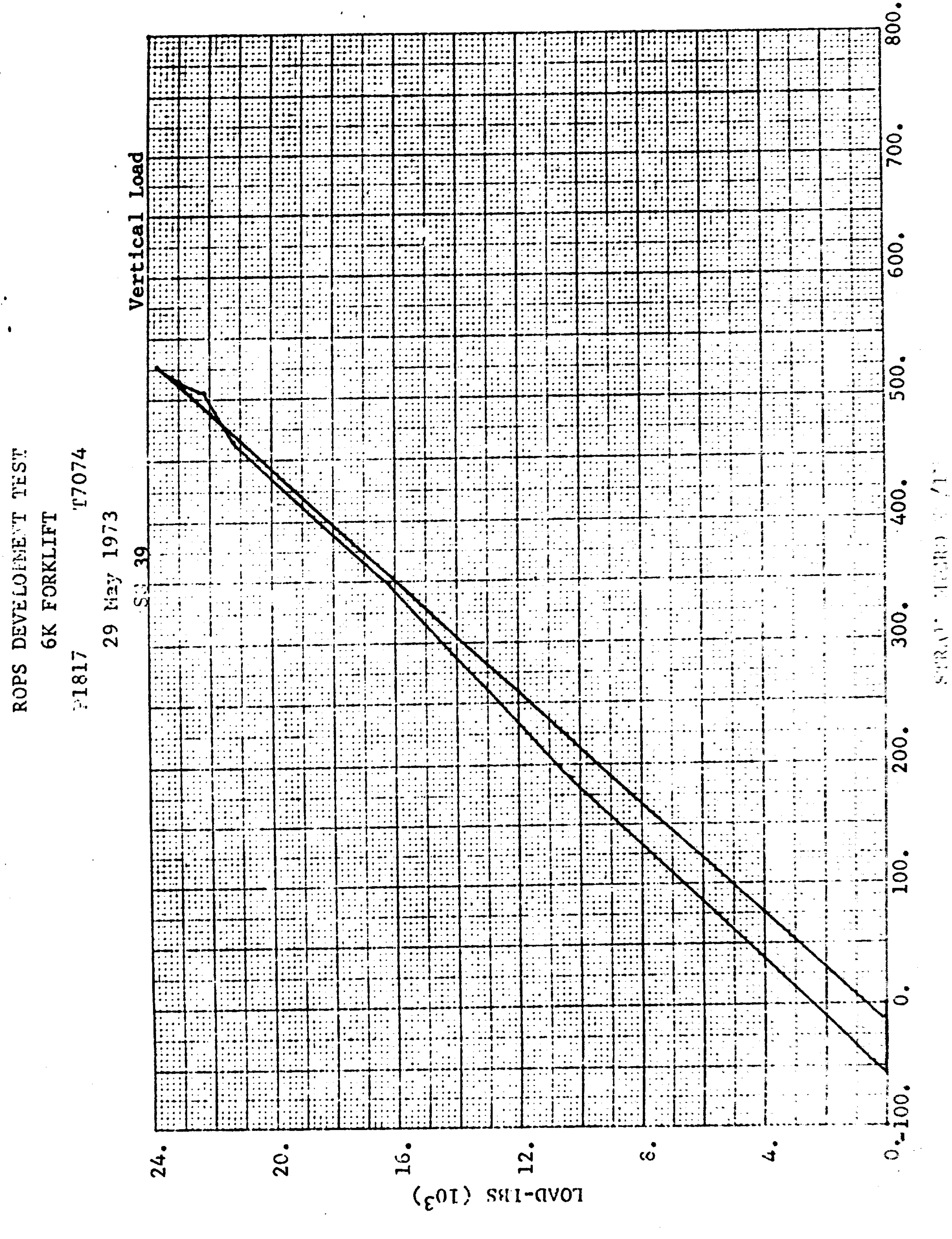

ROPS DEVELOPMENT TEST
6K FORKLIFT
F1817 T7074
29 May 1973
S: 35
Vertical Load
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
-40.
0.
40.
80.
120.
160.
200.
240.
280.
320.

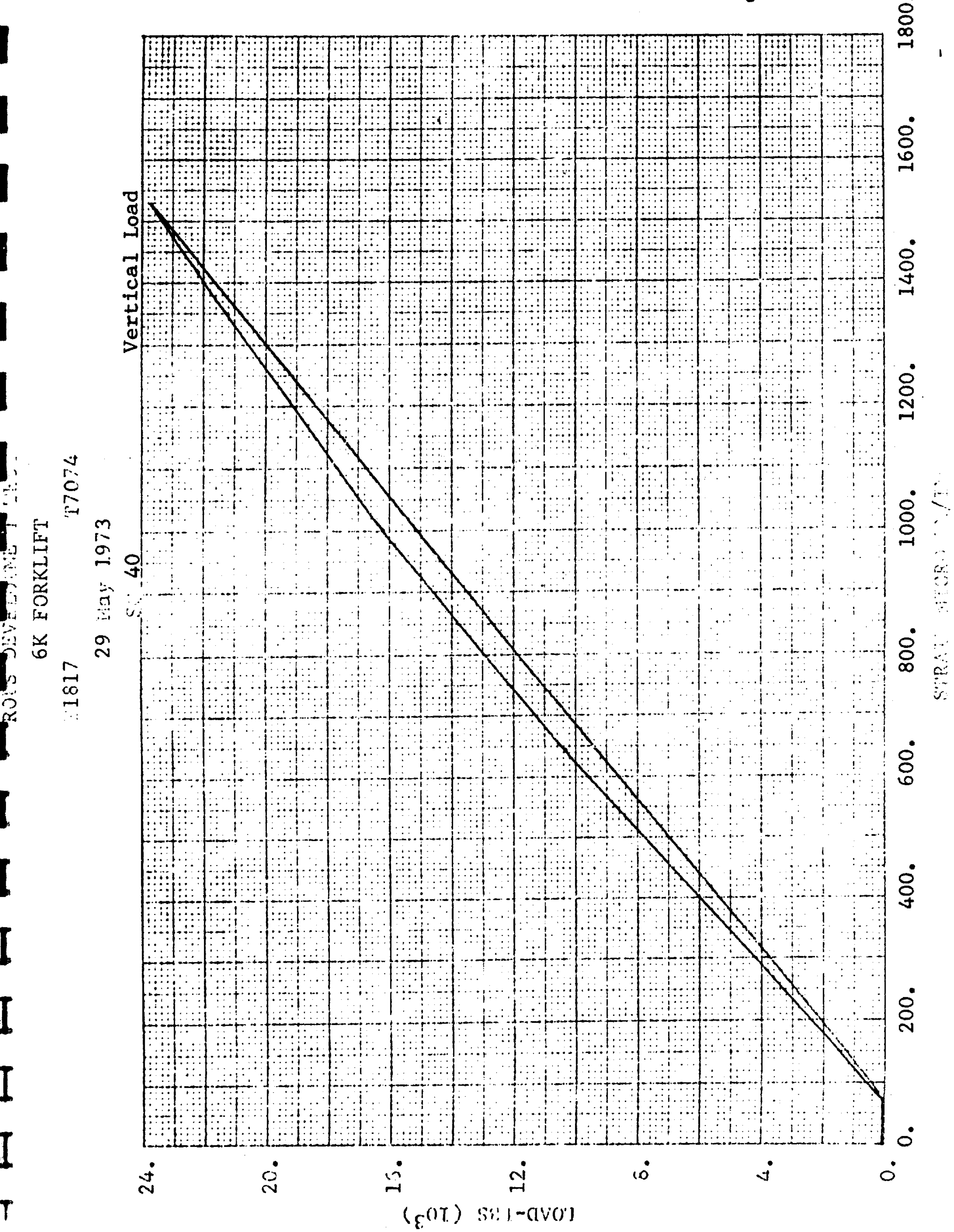

6K FORKLIFT
T7074
29 May 1973
Vertical Load
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.

ROPS DEVELOPMENT TEST
6K FORKLIFT
?1817 T7074
29 May 1973
SG 37 Vertical Load




ROTC DEVELOPMENT TEST
6K FORKLIFT
P1817
T7074
29 May 1973
SG 38
Vertical Load
24.
20.
16.
12.
8.
4.
0.
LOAD-LBS (10^3)
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
STRAIN MICRO IN/IN


ROPS DEVELOPMENT TEST
6K FORKLIFT
P1817 T7074
29 May 1973
SG 39
Vertical Load
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
-100.
0.
100.
200.
300.
400.
500.
600.
700.
800.


6K FORKLIFT
1817
T7074
29 May 1973
Vertical Load
LOAD-LBS (10^3)
24.
20.
16.
12.
8.
4.
0.
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.

APPENDIX 6.4

ANALYSIS OF DEVELOPMENT TEST RESULTS

6K ROPS Test Data Reduction

ROPS Rotation Influence on Side Load

Last valid deflection gage readings occur at 6.00 inch deflection. At this time, side load - 22,180 lbs. This is within 8% of maximum side load of 24,000 lbs. Therefore, a slight increase of this value is reasonable for use at maximum side load.

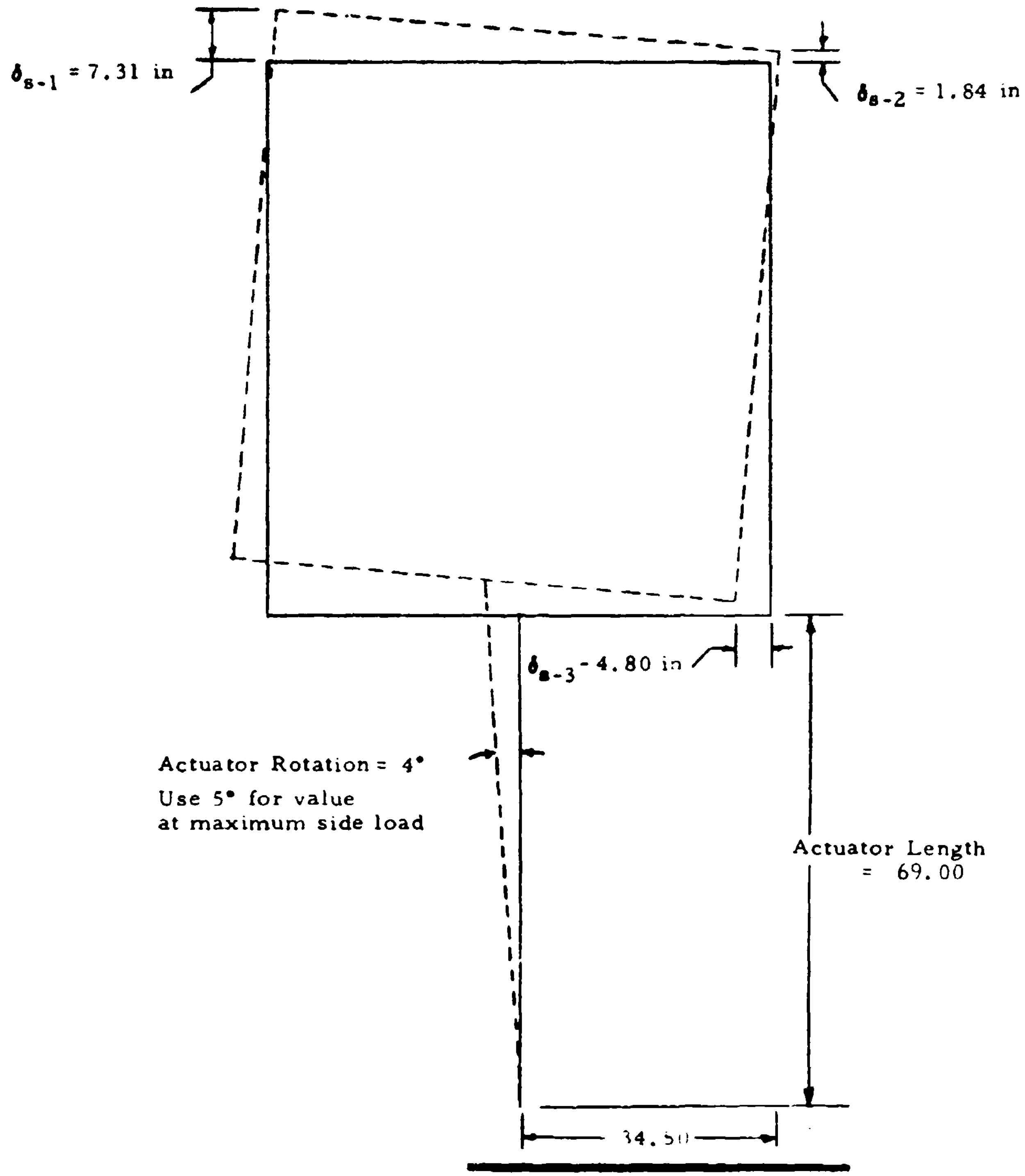
Deflection, S-1 Gage = 8.31-1.00 = 7.31 in.

Deflection, S-2 Gage = 2.84-1.00 = 1.84

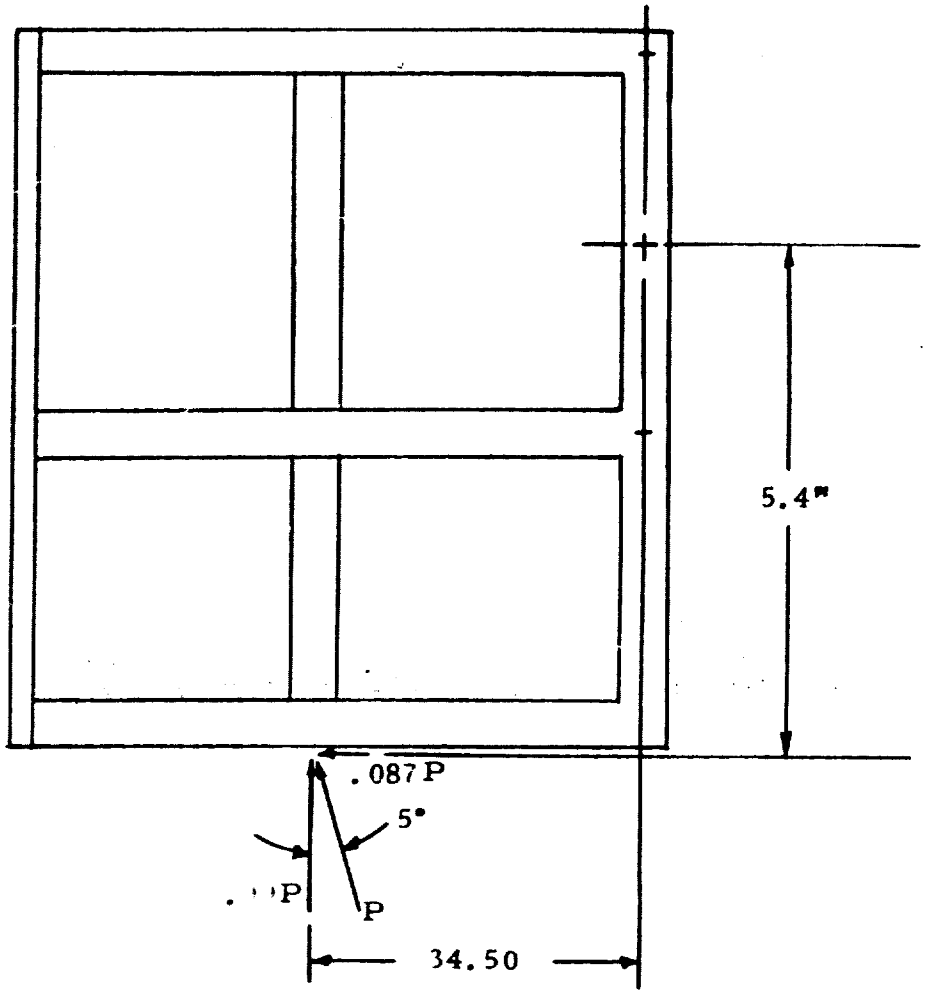
Deflection, S-3 Gage = 6.00-1.20 = 4.80 in.

Deflection gage location and ROPS rotation relative to side load actuator is shown and developed by graphical construction on following page.

6K ROPS Test Data Reduction



6K ROPS Tests Data Reduction
ROPS Rotation Influence on Side Load



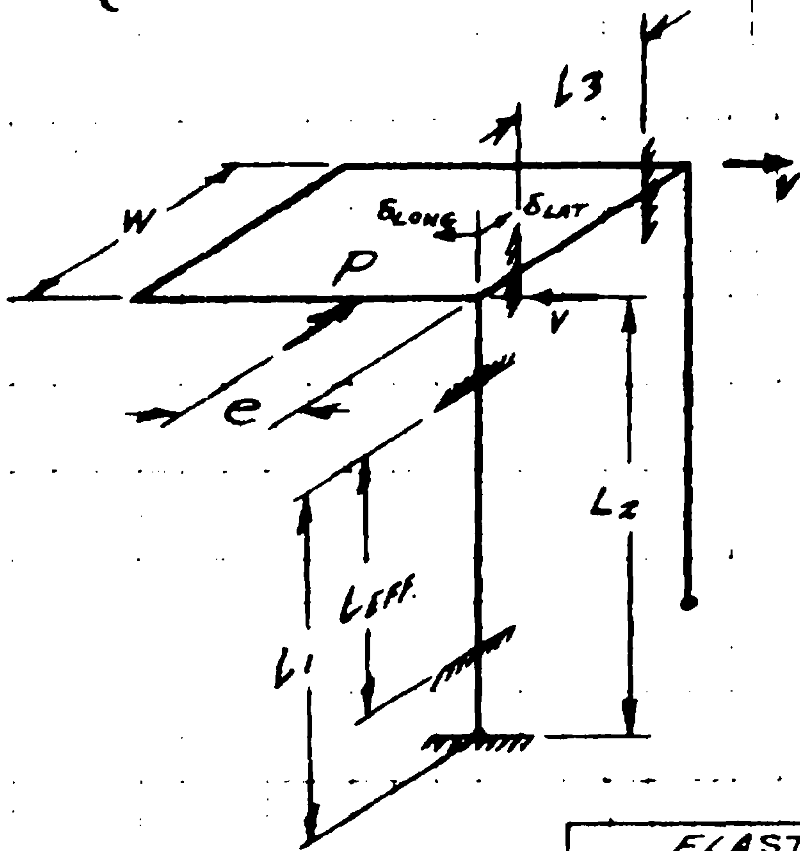
Modify "ROPS load vs. deflection calculation", pg. A-4 for effect of actuator rotation.

$$V_u = \frac{K_{Bu}}{K_{Bu} + K_{tot}} \left(\frac{Pc}{W}\right)_{eff.}$$

$$\left(\frac{Pc}{W}\right)_{eff.} = \frac{(.[illegible]P \times 34.50) + (0.87\ P \times 54.00)}{43.00} = .905\ P$$

$$V_u = \frac{.76}{.76 + .44} \times .905\ P = .573P$$

ROPS LOAD VS. DEFLECTION CALCULATION



L_{EFF} = LENGTH FROM POST FOOT TANGENT TO 1" INTO UPPER GUSSET.

L_1 = DISTANCE FROM TOP OF SOCKET TO 5" INTO UPPER GUSSETT.

L_2 = DISTANCE FROM TOP OF SOCKET TO UPPER STRUCTURE ℄.

L_3 = LENGTH 5" INTO GUSSET ON EACH SIDE.

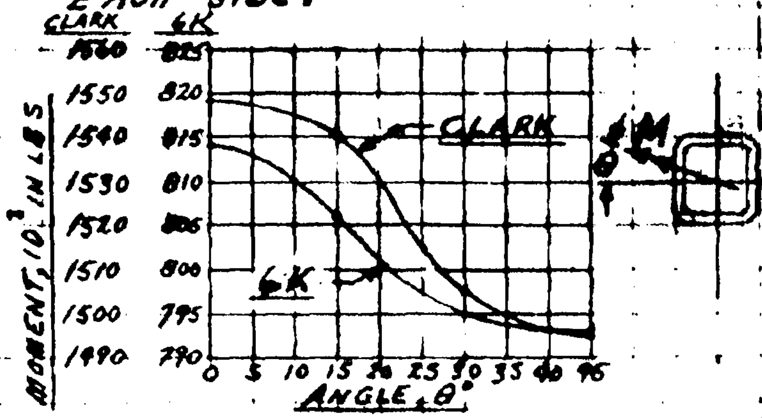


FIG.1 ULT. BEND MOMENT CAPABILITY VS. [illegible] ANGLE

F_{TU} = 77,400 PSI

									10^6 IN LB/IN			ELASTIC CURVE					ULTIMATE CAPABILITY					
													$\frac{PL_1^3}{6EI}$	$\frac{L_2}{\frac{W}{2}}\frac{P L_1^3}{3EI}$	$\frac{V_E L_2^3}{3EI}$	$\delta_{LAT_1}+\delta_{LAT_2}+\frac{e}{W}\cdot\delta_{LONG}$		$\frac{P}{2}\cdot\frac{L_{EFF}}{2}$	$V_U\cdot\frac{L_{EFF}}{2}$	$M_{LAT} + M_{LONG}$		$\frac{M_{FIG.1}}{COEF.\ P}$
SIZE	I	J	L_{EFF}	L_1	L_2	L_3	W	e	K_{TOR}	K_{BE}	K_{BU}	V_E	δ_{LAT_1}	δ_{LAT_2}	δ_{LONG}	$\Sigma\delta$, IN.	V_U	M_{LAT}	M_{LONG}	M	θ	P, LB.
6×6×½	68.3	83.[illegible]	36.5	49	61	46	72	14.3	.83	1.33	.25	.122 P	.0000140 P	.0000092 P	.0000066 P	.0000206 P	.176 P	9.12 P	3.21 P	9.80 P	19°	158,000
5×5×[illegible]	21.9	10.3	75.5	85	92.5	27	43	36	.94	.10	.76	.155 P	.000161 P	.000019 P	.000064 P	.00029 P	.530 P	18.90 P	20.06 P	27.5 P	13°	28,900

$$K_{TOR} = \frac{1}{\delta} = \frac{1\ IN\ LB}{R\frac{TL}{JG}} = \frac{1\ IN\ LB}{\frac{W}{2}\cdot\frac{1}{2}\cdot\frac{L_2}{JG}}$$

$$K_{BE} = \frac{1}{\delta} = \frac{1\ IN\ LB}{\frac{1}{W}\cdot\frac{L_2^3}{3EI}}$$

$$K_{BU} = \frac{1}{\delta} = \frac{1\ IN\ LB}{\frac{1}{W}\cdot\frac{L_{EFF}^3}{12EI}}$$

$$V_E = \frac{K_{BE}}{K_{BE}+K_{TOR}}\left(\frac{Pe}{W}\right) \qquad V_U = \frac{K_{BU}}{K_{BU}+K_{TOR}}\left(\frac{Pe}{W}\right) \qquad P_S = \frac{P}{2}\cdot\frac{L_2}{\frac{W}{2}}$$

6K Test Data Reduction

ROPS Rotation Influence on Side Load

$$M_{lat} = \frac{P \cdot L_{eff}}{4} = \frac{.99P \times 75.5}{4} = 18.70\ P$$

$$M_{long} = V_u \frac{L_{eff}}{2} + \frac{.087P\ (L_2 - 7.00)}{2}$$

$$= .573P \cdot \frac{75.5}{2} + \frac{.087P\,(85.5)}{2} =$$

$$= 21.6P + 3.7P = 25.3P$$

$$M = M_{lat} \mathrel{+\!\!\rightarrow} M_{long} = 18.70\ P \mathrel{+\!\!\rightarrow} 25.3P = 31.5P \text{ at } 31^\circ$$

From Page A-4 moment capability at 31°

$$= 795,000 \text{ in. lbs for material } F_{tu} = 77,400 \text{ psi}$$

Coupon tests of 6K ROPS test tubes average 75,600 psi. Moment capability for this material

$$= \frac{75,600}{77,400} \times 795,000 = 776,000 \text{ in lbs}$$

$$P = \frac{776,000}{31.5} = 24,600 \text{ lbs}$$

1. Maximum side load developed by test = 24,000 lbs
2. Deflected shape of test was very similar to deflected shape shown on page A-2 where right ROPS vertical leg had essentially no longitudinal deflection.

Two points above indicate reduced side load is contributable to actuator rotation.

APPENDIX 6.5

STRUCTURAL ANALYSIS OF PROTOTYPE UNIT

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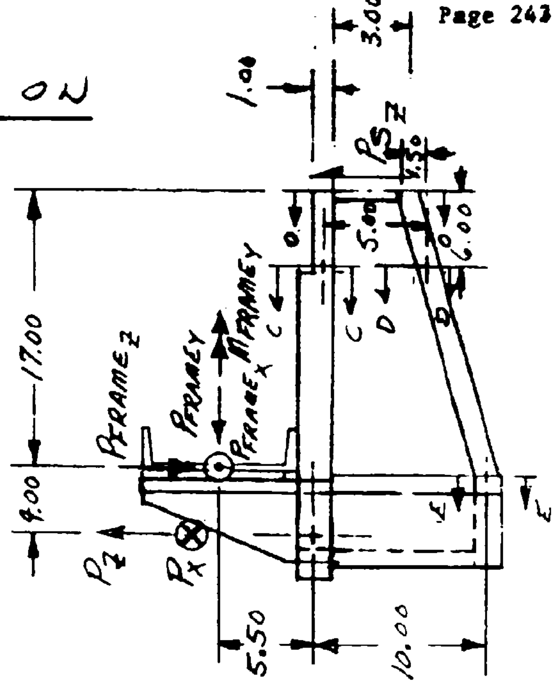
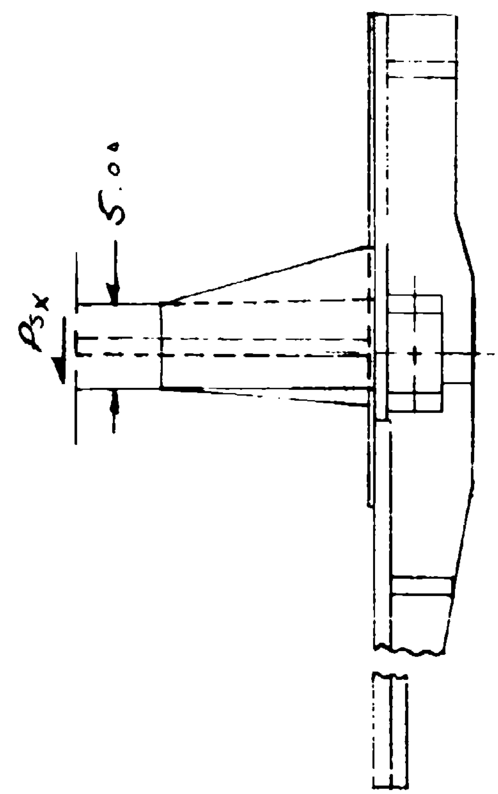
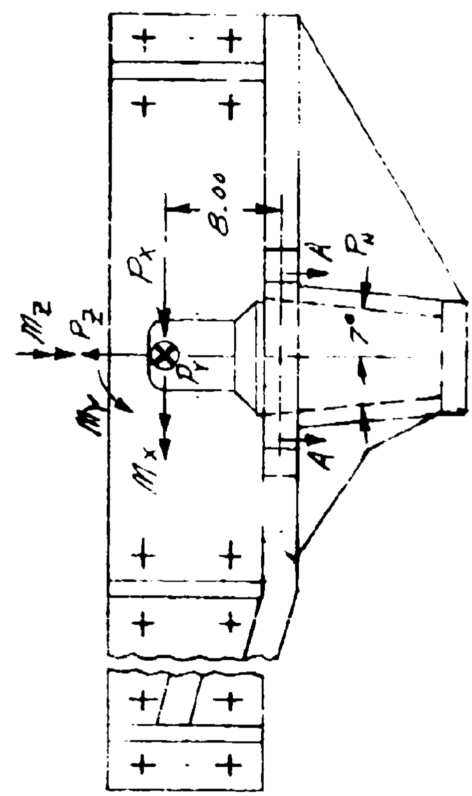
6/16/73

6K ROPS - BOLT ON







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5/23/73

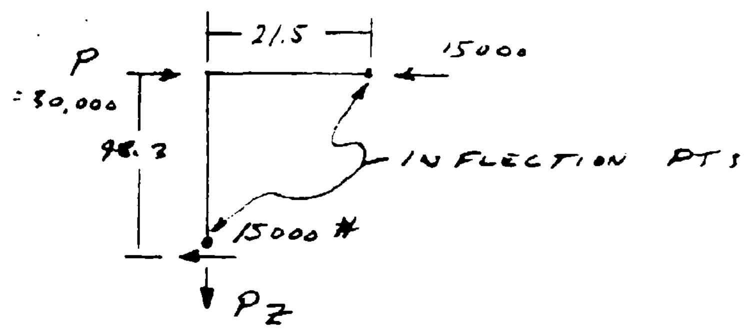
6K ROPS - BILT ON

LOADS FOR $F_{TU} = 77.4$ KSI $P = 28{,}900$ #
(REF ROPS LOAD VS. DEFLECTION CALCULATION)

$$P_{MAX} = \frac{80}{77.4} \times 28{,}900 = 30{,}000 \text{ \#}$$

$$P_X = V_U = .53 \times 30{,}000 = 15{,}900 \text{ \#}$$

$$P_Y = .5P = \quad 15{,}000 \text{ \#}$$



$$P_Z = \frac{45.3}{21.5} \times 15000 = 31{,}600 \text{ \#}$$

$$M_X = 18.90 \times 30{,}000 = 567{,}000 \text{ IN\#}$$

$$M_Y = 20.00 \times 30{,}000 = 600{,}000 \text{ IN\#}$$

$$M_Z = \frac{K_{TOR}}{K_{TOR} + K_{\theta_U}} \cdot \frac{Pe}{2} = \frac{.44}{.44 + .76} \cdot \frac{30{,}000 \times 36}{2} = 199{,}000 \text{ IN\#}$$

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6K ROPS - BOLT ON

LOADS IN SOCKET: (REF PGS 1, 2, 3)

$$P_x = 15,900 \#$$
$$P_y = 15,000 \#$$
$$P_z = 31,600 \#$$
$$M_x = 567,000 + (\overset{120,000}{8.00 \times 15,000}) = 687,000 \text{ IN}\#$$
$$M_y = 600,000 + (\overset{127,000}{8.00 \times 15,900}) = 727,000 \text{ IN}\#$$
$$M_z = 199,000 \text{ IN}\#$$

IN BEAM:

$$P_{S_z} = \frac{687,000 + (4 \times 31,600) - (5.50 \times 15000)}{17.00} = 43,000 \#$$

$$P_{S_x} = \frac{199,000 + (4.00 \times 15,900)}{17.00} = 15,400 \#$$

EXTERNAL LOADS:

$$P_{FRAME_Y} = P_Y = 15000 \#$$

$$P_{FRAME_X} = P_X + P_{S_X} = 15,900 + 15,400 = 31,300 \#$$

$$P_{FRAME_Z} = P_Z + P_{S_Z} = 31,600 + 43,000 = 74,600 \#$$

$$M_{FRAME_Y} = 727,000 - (\overset{87,500}{5.50 \times 15,900}) = 639,500 \text{ IN}\#$$

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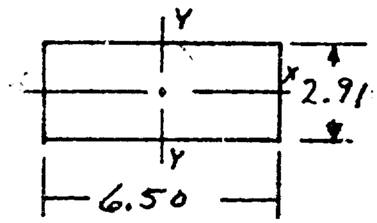
SECTION A-A (PG. 1)



$A = 18.9 \text{ IN}^2$

$I_{XX} = 13.3 \text{ IN}^4$

$I_{YY} = 66.5 \text{ IN}^4$

OPENING AT TOP OF SOCKET
= 3.25 X 7.00.

FOOT WIDTH = 3.25 − .34 = 2.91 IN

FOOT LENTH AT TOP OF SOCKET
= 7.00 − .250 = 6.75.
FOOT LENGTH ONE INCH DOWN INTO SOCKET = 6.75 − 2×1.00 TAN 7°
= 6.75 − .25 = 6.50 IN.

$M_X = 687{,}000$ IN #
$M_Y = 727{,}000$ IN #
$M_Z = 199{,}000$ IN # (PG. 5)

$$f_{bx} = \frac{687{,}000 \times 1.46}{13.3} = 75{,}000 \text{ PSI}$$

$$f_{bY} = \frac{727{,}000 \times 3.25}{66.5} = 35{,}500 \text{ PSI}$$

$$f_{s_T} = \frac{M_Z(3a + 1.8b)}{8a^2b^2} \qquad a = \frac{6.50}{2} = 3.25 \quad b = \frac{2.91}{2} = 1.46$$

$$f_{s_T} = \frac{199{,}000(\overbrace{3 \times 3.25 + 1.8 \times 1.46}^{12.38})}{\underbrace{8 \times 3.25^2 \times 1.46^2}_{180}} = 13{,}700 \text{ PSI}$$

$$\Sigma f_b = 75{,}000 + 35{,}500 = 110{,}500 \text{ PSI}$$

F_{TU} (4340 STEEL, 125 KSI H.T.): 125 KSI

$F_{bU} = 1.47 \times 125{,}000 = 183{,}000$ PSI

$$S.F. = \frac{183{,}000}{110{,}500} = \underline{\underline{1.67}}$$

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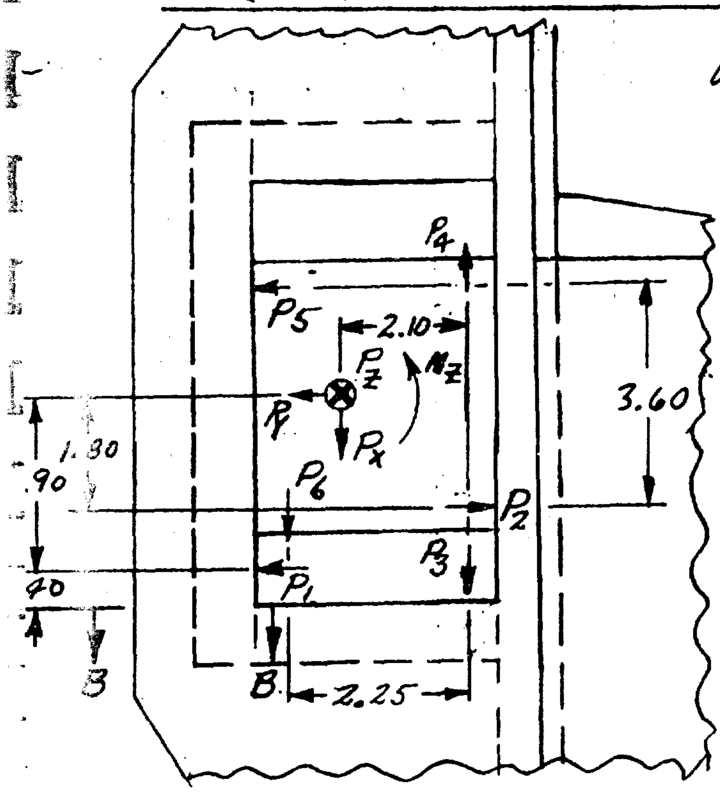
6/11/73

6K ROPS – BOLT ON



USE REVERSE LOADS. FROM PG. 3:

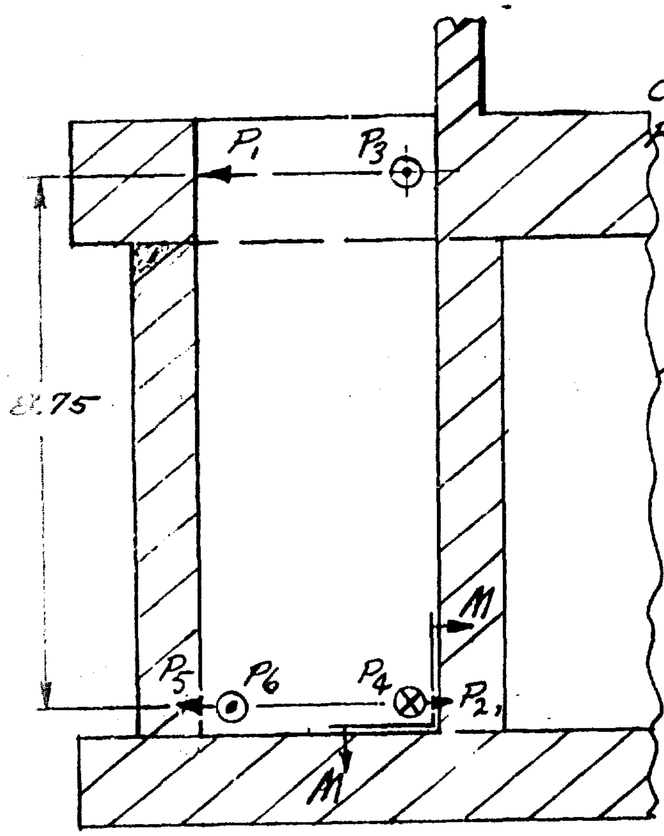
DUE TO P_X,
$P_3 \qquad = 15,900\#$

DUE TO P_Y,
$P_1 \qquad = 15,000\#$

DUE TO P_Z,
$P_N = \frac{31,600}{\sin 7° \times 2} \qquad = 130,000\#$ (PG. 1)

DUE TO M_X,
$P_1 = \frac{687,000}{8.75} \qquad = 78,500\#$
$P_2 \qquad = 78,500\#$

DUE TO M_Y,
$P_3 = \frac{727,000}{8.75} \qquad = 83,100\#$
$P_4 \qquad = 83,100\#$



CONSIDERING SOCKET LOADS ON ROPS FOOT,

$M_Z = 199,000 + 2.90(15,000 + 78,500)$
$\quad - 1.80(78,500) + 2.10(15,900)$
$\quad = 362,000 \text{ in}\#$

DUE TO M_Z,
ASSUMING M_Z REACTED BY P_2 & P_5,
$P_2 = \frac{362,000}{3.6} = 100,000\#$
$P_5 \qquad = 100,000\#$

SUMMING LOADS:
$P_1 = 15,000 + 78,500 = 93,500\#$
$P_2 = 78,500 + 100,000 = 178,500\#$
$P_3 = 15,900 + 83,100 = 99,000\#$
$P_4 = \qquad 83,100\#$
$P_5 = \qquad 100,000\#$
$P_N = \qquad 130,000\#$
P_1 . [illegible]

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6/18/73

6K ROPS - BOLT ON

ASSUMING M_Z REACTED BY P_4 & P_6,

$P_4 = \frac{362000}{2.25} = 161,000$ #

$P_6 = 161,000$ #

SUMMING LOADS:

P_1	$= 15,000 + 78,500$	$= 93,500$ #
P_2	$=$	78,500 #
P_3	$= 15,900 + 83,100 =$	99,000 #
P_4	$= 83,100 + 161,000$	244,100 #
P_5	$=$	0 #
P_6	$=$	161,000 #

SECTION M-M (PG. 5)

SHEAR CHECK OF 1.50" SOCKET EDGE PLATE FOR P_4.

$P_4 = 244,000$ # (REF. ABOVE)

ASSUME 3" ALONG SOCKET BASE AND 2" ALONG SOCKET INBOARD PLATE EFFECTIVE IN SHEAR.

$A_S = 5.00 \times 1.50 = 7.50 \text{ IN}^2$

$f_s = \frac{244000}{7.50} = 33,000$ PSI

$F_{SU} = .64 \times 70,000 = 45,000$ PSI

$S.F._U = \frac{45000}{33,000} = \underline{\underline{1.36}}$

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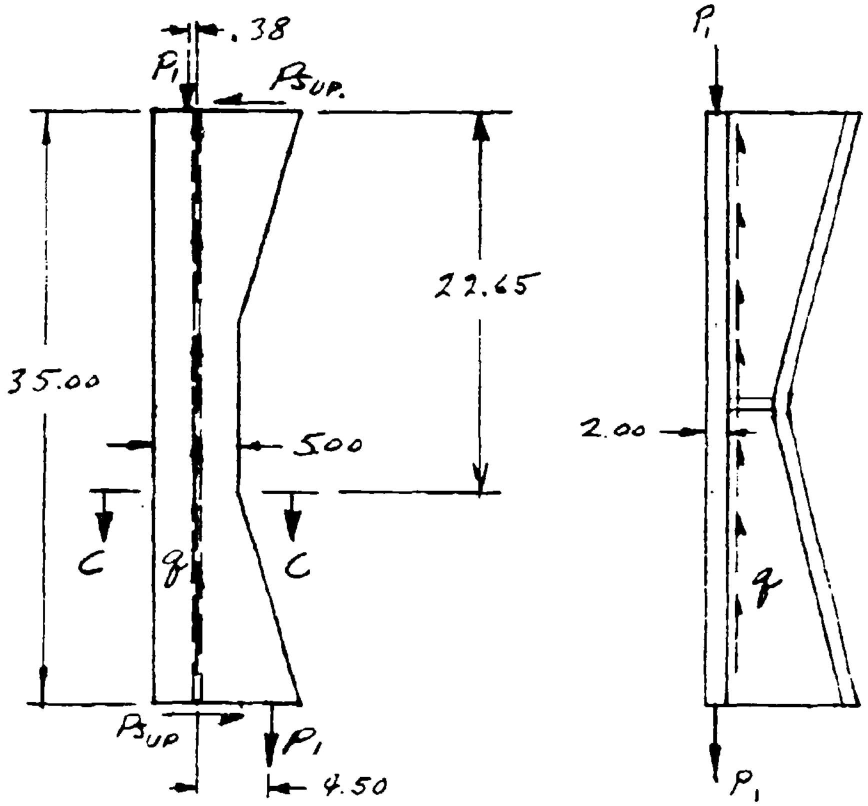
7/9/73

6K ROPS - BOLT ON

UPPER CROSS BEAM LOADS



$P_1 = 93,500$ # (PG. 5)

$$q = \frac{93,500 + 93,500}{35.00} = 5,340 \text{ \#/IN}$$

$$P_{SUP} = \frac{(4.50 - .38) \times 93,500}{35.00} = 11,000 \text{ \#}$$

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6/18/73

GK ROPS - BOLT ON

SECTION B-B (PG. 5)

$P_1 = 93,500\ \#$ (PG. 5)

$M = .40 \times 93500 = 37,400$ IN #

$f_b = \dfrac{6 \times 37400}{2 \times \overline{1.75}^2} = 37000$ PSI

$F_{b_Y} = 1.28 \times 38,000 = 48,000$ PSI

$S.F._Y = \dfrac{48000}{37000} = \underline{1.30}$

$A_S = 2.00 \times 1.75 = 3.50\ IN^2$

$f_S = \dfrac{93500}{3.50} = 27,000$ PSI

$F_{S_U} = 45,000$ PSI

$S.F._U = \dfrac{45000}{27000} = \underline{1.66}$

SECTION C-C (PG. 6a)

$q = 5,340\ \#/IN$
$P_{UP} = 11,000\ \#$ } PG. 6a.

$M_{CC} = (22.65 \times 11,000) + (.38 \times 93,500)$
$= 284,600$ IN #

$P_T = (22.65 \times 5,340) - 93,500 = + 27,500\ \#$

$f_b = \dfrac{6 \times 284,000}{2.00 \times \overline{5.00}^2} = 34,000$ PSI

$f_T = \dfrac{27,500}{1.00 \times 5.00} = 2,730$ PSI

$F_{T_U} = 38,000$ PSI -- 38000

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6/18/73

6K ROPS - BOLT ON

SECTION D-D (PG. 1)

SECTION D-D REACTS P_{S_X} & P_{S_Z}.

$$\left.\begin{array}{l} P_{S_Z} = 43{,}000\ \# \\ P_{S_X} = 15{,}400\ \# \end{array}\right\}\ \text{PG. 3}$$

DUE TO P_{S_Z}, $P_{TENS} = P_{cc} = 52000\ \#$ (PG. 7)

$$A_{TENS} = 5.0 \times 1.5 = 7.5\ IN^2$$

$$f_T = \frac{52000}{7.5} = 7000\ PSI$$

SECTION D-D REACTS ALL OF P_{S_X}.

$$M = 6.00 \times 15{,}400 = 92{,}500\ IN\#$$

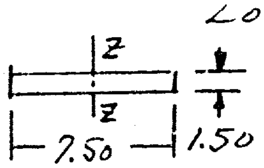
$$f_b = \frac{6 \times 92{,}500}{1.5 \times \overline{5.0}^2} = 15000\ PSI$$

$$F_{TY} = 38{,}000\ PSI$$

$$S.F._Y = \frac{38000}{7000 + 15{,}000} = \underline{\underline{1.73}}$$

SECTION E-E (PG. 1)

LOADING SAME AS D-D ABOVE.



$$P_{TENS} = \frac{17.00}{10.00} \times 43{,}000 = 73{,}000\ \#$$

$$M_{ZZ} = 17.00 \times 15{,}400 = 262{,}000\ IN\#$$

$$f_T = \frac{73000}{7.5 \times 1.5} = 6{,}500\ PSI$$

$$f_b = \frac{6 \times 262000}{1.5 \times \overline{7.5}^2} = 18{,}600\ PSI$$

$$S.F._Y = \frac{38{,}000}{6500 + 18600} = \underline{\underline{1.51}}$$

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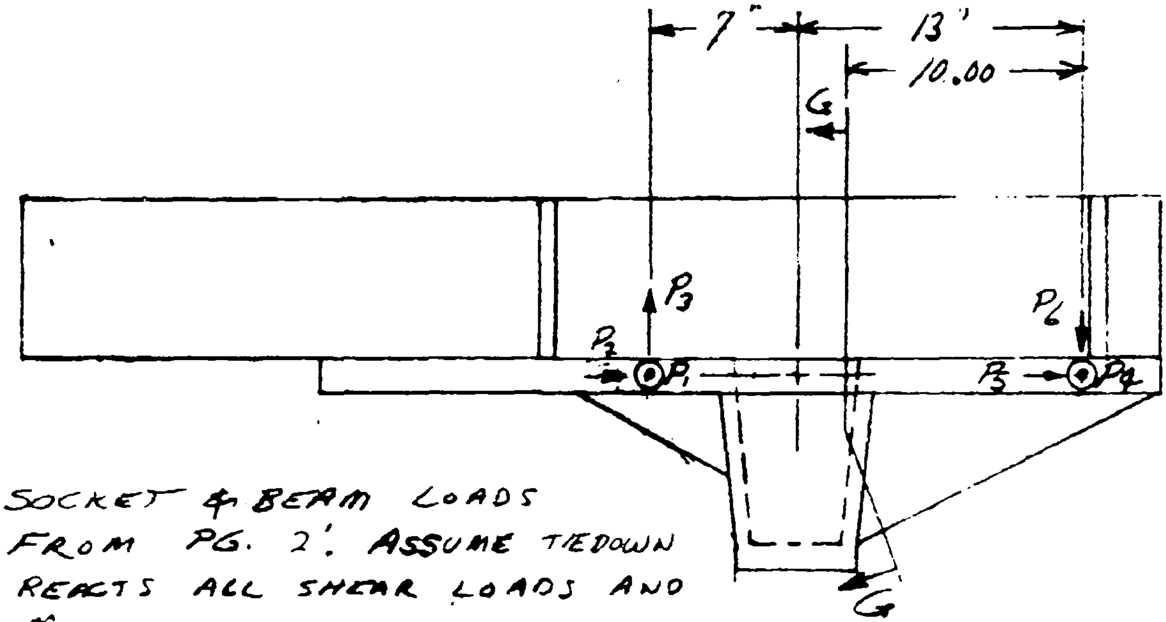
7/20/73

6K ROPS—BOLT ON

FRAME REINFORCEMENT, TEST CONDITION



SOCKET & BEAM LOADS FROM PG. 2. ASSUME TIEDOWN REACTS ALL SHEAR LOADS AND M_Y.

$$P_1 = \frac{(13 \times 16650)}{20} = 10{,}800\ \#$$

$$P_2 = 0 \rightarrow (21{,}600 + 24{,}800) = 0 \rightarrow 46{,}400\ \#$$

$$P_3 = \frac{-13(30{,}400 + 51{,}800) + 1{,}103{,}000}{20} = 1{,}700\ \#$$

$$P_4 = \frac{(7 \times 16650)}{20} = 5850\ \#$$

$$P_5 = 0 \rightarrow 46{,}400\ \#$$

$$P_6 = \frac{7(30{,}400 + 51{,}800) + 1{,}103{,}000}{20} = 83{,}400\ \#$$

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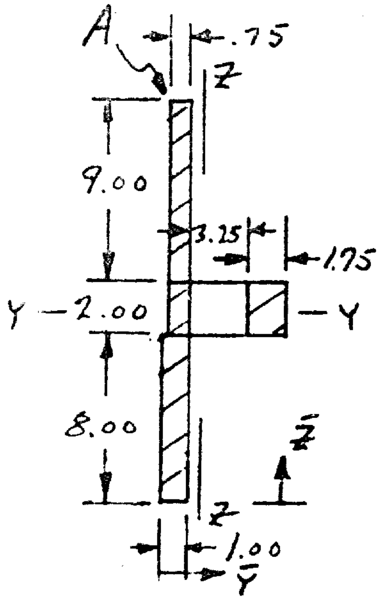
7/6/73

6K KOPS - BOLT ON

SECTION G-G (PG. 9)



$A = 19.7\ IN^2$
$\bar{Z} = 8.85\ IN$
$I_{YY} = 493\ IN^4$
$\bar{Y} = 1.37\ IN$
$I_{ZZ} = 61.8\ IN^4$

$P_4 = 5{,}850$ #
$P_5 = 0 \rightarrow 46{,}400$ #
$P_6 = 83{,}900$ #
} PG. 9

$M_{YY} = 10.00 \times 83{,}900 = 839{,}000$ IN#

$M_{ZZ} = 10.00 \times 5850 = 58{,}500$ IN#

ASSUME REVERSED LOADS.

AT POINT A,

$f_c = \dfrac{46{,}400}{19.7} = 2{,}400$ PSI (COMP)

$f_{bYY} = \dfrac{839{,}000 \times 10.15}{493} = 17{,}300$ PSI (COMP)

$f_{bZZ} = \dfrac{58{,}500 \times 1.12}{61.8} = 1{,}000$ PSI (COMP)

$\Sigma f_c = 2{,}400 + 17{,}300 + 1{,}000 = 20{,}700$ PSI

FROM S.M. # 126, FIG. 12, FOR

$\dfrac{b}{t} = \dfrac{9.00}{.75} = 12$, F_{cc} IS APPROX.

24,000 PSI.

$S.F._U = \dfrac{24000}{20{,}700} = \underline{\underline{1.16}}$

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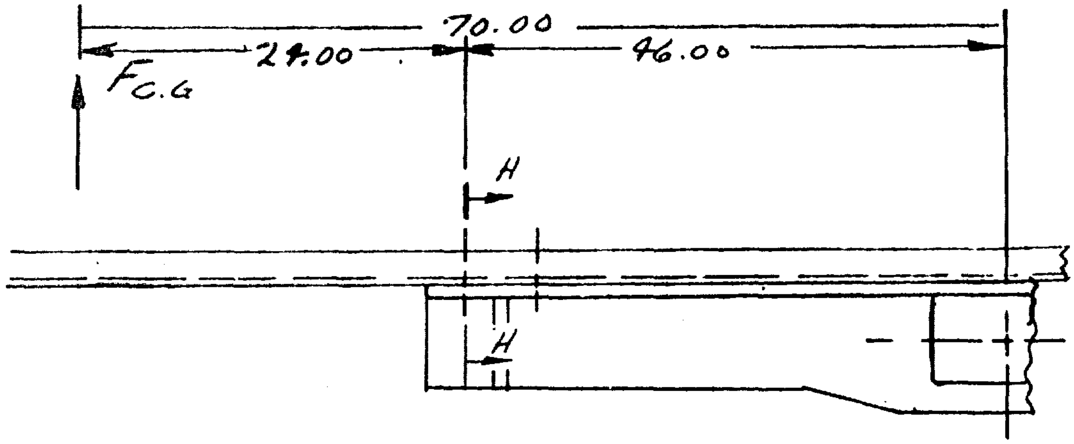
5/28/73

6K ROPS - BOLT ON

FRAME ROLL OVER ANALYSIS



WITH THE VEHICLE ENGINE, TRANSMISSION, COUNTERWEIGHT AFT WHEELS & DIFFERENTIAL ATTACHED TO THE FRAME IN THE AREA OF THE ROLL OVER STRUCTURE, ASSUME 1/2 OF THE ROLL OVER FORCE IS ORIGINATED FROM THE VEHICLE SECTION WHICH IS FORWARD OF THE FRAME REINFORCEMENT. THIS FORCE HAS TO BE CARRIED BY THE UNREINFORCED FRAME ALONE. FOLLOWING IS THE ANALYSIS OF THE UNREINFORCED FRAME FOR THE FORWARD MASS LOAD TRANSFER. THE C.G. OF THE FORWARD MASS IS APPROX. 70 IN FORWARD OF THE ROLL OVER STRUCTURE.

ROLL OVER SIDE LOAD = 15,000 #
(REF. 6K ROPS PDR, PG. 7)

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5/28/73

SECTION H-H (PG 11)

$$F_{C.G.} = \frac{15000}{4} = 3750 \text{ \#/SIDE}$$

$$M = 24.00 \times 3750 = 90,000 \text{ IN\#}$$

CHANNEL: $I = 1.9 \text{ IN}^4$
$\bar{Y} = 2.485 - .59 = 1.895$

$$f_b = \frac{90,000 \times 1.895}{1.90} = 90,000 \text{ PSI}$$

$$F_{bu} = 1.5 \times 70,000 = 105,000 \text{ PSI}$$

$$S.F._U = \frac{105,000}{90,000} = \underline{\underline{1.17}}$$

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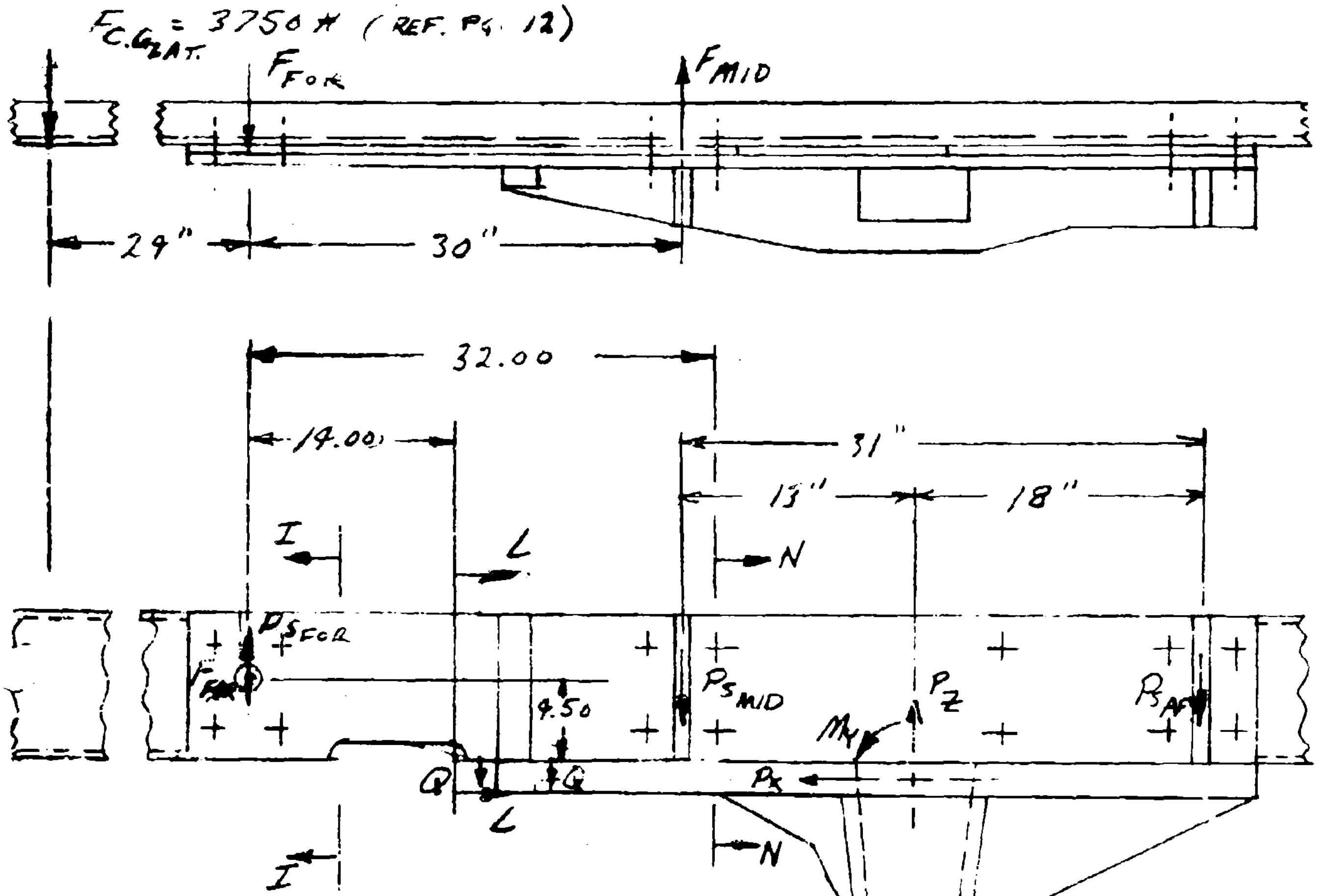
6/19/73

6K ROPS - BOLT ON, ROLL OVER CONDITION



BOLT SHEAR LOADS
SOCKET & BEAM LOADS, PG. 21.

DUE TO $P_x + P_{S_x} = 21{,}600 + 24{,}800 = 46{,}400\#$,

$$P_S = \frac{46{,}400}{14} = 3300\# \text{ (HORIZONTAL)}$$

DUE TO $P_Z + P_{S_Z} = 30{,}400 + 51{,}800 = 82{,}200\#$,

$$P_{S_{MID}} = \frac{18 \times 82200}{31} = 47{,}700\#$$

$$P_{S_{AFT}} = \frac{13 \times 82200}{31} = 34{,}500\#$$

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6K ROPS - BOLT ON, ROLL OVER COND.

DUE TO M_Y = 1,103,000 IN #

$$P_{S_{FOR}} = \frac{+1,103,000}{61} = +18,100 \#$$

$$P_{S_{AFT}} = +18,100 \#$$

TOTAL BOLT SHEAR LOADS:

$$P_{S_{FOR}} = +18,100 \#$$

$$P_{S_{MID}} = 47,700 \#$$

$$P_{S_{AFT}} = 34,500 + 18,100 = 52,600 \#$$

$$P_{HORIZONTAL} = 3300 \# \cdot BOLT$$

BOLT SHEAR CHECK - $\frac{3}{4}$ DIA BOLT

$P_{S_{AFT}}$ = 52,600 # (REF. ABOVE)

$$P_S = \frac{52600}{4} + 3300 = 13,500 \#/BOLT$$

JOINT CRITICAL IN BEARING IN .28" CHANNEL.

$$A_{BR} = .28 \times .75 = .21 \ IN^2$$

$$F_{BR} = \frac{13500}{.21} = 64,000 \ PSI$$

$$F_{BR_U} \cong 90,000 \ PSI$$

$$S.F._Y = \frac{90,000}{64,000} = \underline{\underline{1.40}}$$

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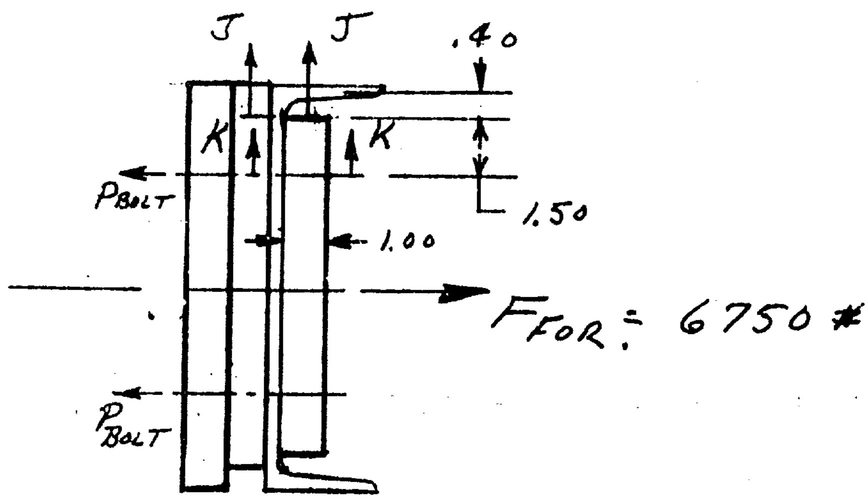
6K ROPS- BOLT ON - ROLL OVER ANALYSIS

VIEW I-I (PG. 13)



SECTION J-J (ABOVE)

$F_{C.G.} = 3750$ # (PG. 12)

FROM PG. 13,

$F_{FOR.} = 54/30 \times 3750 = 6{,}750$ #

$F_{MID} = 24/30 \times 3750 = 3000$ #

FOR FOUR BOLTS:

$P_{BOLT} = \frac{6750}{4} = 1690$ #

$M_{JJ} = .4 \times 1690 = 675$ IN #

ASSUME .28" THICK × 2.00" WIDE SECTION EFFECTIVE AT J-J.

$f_b = \frac{6 \times 675}{2 \times .28^2} = 26{,}000$ PSI

$F_{TU} = 70{,}000$ PSI

$S.F. = \frac{70000}{26000} = \underline{2.70}$

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6/7/73

6K ROPS - BOLT ON

SECTION K-K (PG. 15)

$P_{BOLT} = 1690$ # (REF. PREV. PG.)

$M_{KK} = 1.50 \times 1690 = 2{,}540$ IN #

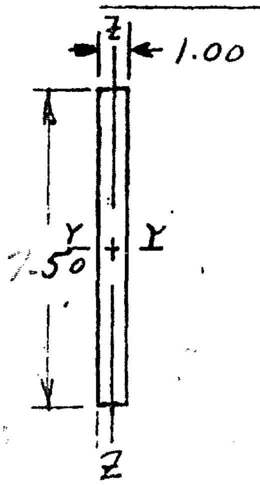
ASSUME 1" THICK × 2" WIDE SECTION EFFECTIVE.

$f_b = \dfrac{6 \times 2540}{2 \times 1^2} = 7{,}600$ PSI

S.F. = HIGH

USE 1" BACKUP AT CENTER & ENDS
OF FRAME REINFORCEMENT.

SECTION L-L (PG. 11)



$P_{S\,FOR.} = 18{,}100$ # (PG. 14)
$F_{FOR.} = 6{,}750$ # (PG. 15)

$M_{YY} = 14.00 \times 18100 = 253{,}000$ IN #

$M_{ZZ} = 14.00 \times 6{,}750 = 94{,}500$ IN #

$f_{b_{YY}} = \dfrac{6 \times 253000}{1.00 \times 7.5^2} = 27{,}000$ PSI

$f_{b_{ZZ}} = \dfrac{6 \times 94{,}500}{7.50 \times 1.00^2} = 75{,}000$ PSI

$F_{b_U} = 1.50 \times 70{,}000 = 105{,}000$ PSI

$S.F._U = \dfrac{105000}{27{,}000 + 75000} = \underline{1.03}$

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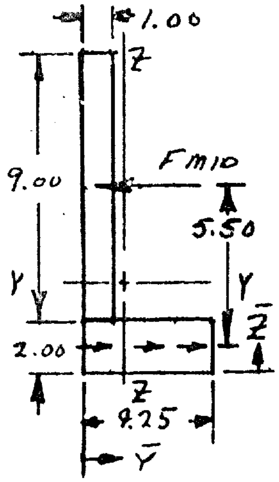
7/7/73

6K ROPS – BOLT ON, ROLL OVER ANALYSIS

SECTION N-N (PG. 11)



$P_{S_{FOR}} = +11,900$ # } PG. 12
$P_{S_{MID}} = +17,300$ #

$F_{FOR} = 6,750$ # } PG. 15
$F_{MID} = 3000$ #

$M_{YY} = 32.00 \times 11,900 = 381,000$ IN#

$M_{ZZ} = 32.00 \times 6750 = 216,000$ IN#

F_{MID} IS APPLIED 5.5 IN. FROM SHEAR WEB AS SHOWN.

$A = 17.5\ IN^2$
$\bar{Z} = 3.83$ IN
$I_{YY} = 195\ IN^4$
$\bar{Y} = 1.28$ IN
$I_{ZZ} = 25\ IN^4$
$\Sigma \alpha b t^2 = 7.0\ IN^3$

SECTION TORSION $= 5.50 \times 3000 - M_{ZZ} \tan 12°$
$= 16,500 - 216,000 \tan 12°$
$= 16,500 - 46,000$

ASSUME ONE OF THE TORSION FACTORS MAY BE ZERO.

TORSION = 46,000 IN#

$f_{b_{YY}} = \dfrac{381,000 \times 7.17}{195} = 14,000$ PSI

$f_{b_{ZZ}} = \dfrac{216,000 \times (4.25 - 1.28)}{25} = 26,000$ PSI

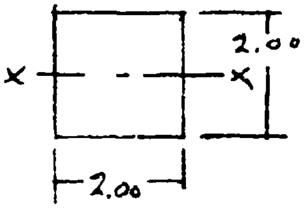
$f_{S_T} = \dfrac{46,000}{7.0} = 6,600$ PSI

SECTION CRITICAL FOR $f_{b_{ZZ}}$

$F_{b_U} = 105,000$ PSI (P. 16)

$S.F._U = \dfrac{105000}{26000} = \underline{\underline{4.0}}$

SECTION Q-Q (PG. 13)



$F_{FOR} = 6750\ \#$ (PG. 15)

$M_{xx} = 4.50 \times 6750 = 30{,}400$ IN #

$$f_{b_x} = \frac{6 \times 30{,}400}{2.00 \times \overline{2.00}^2} = 23{,}000 \text{ PSI}$$

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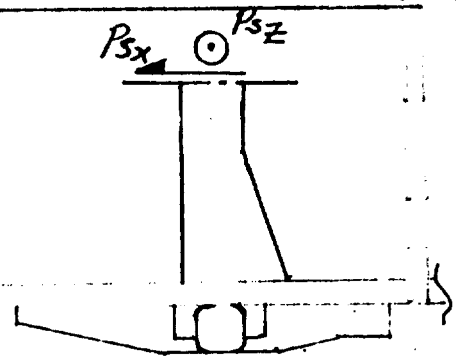
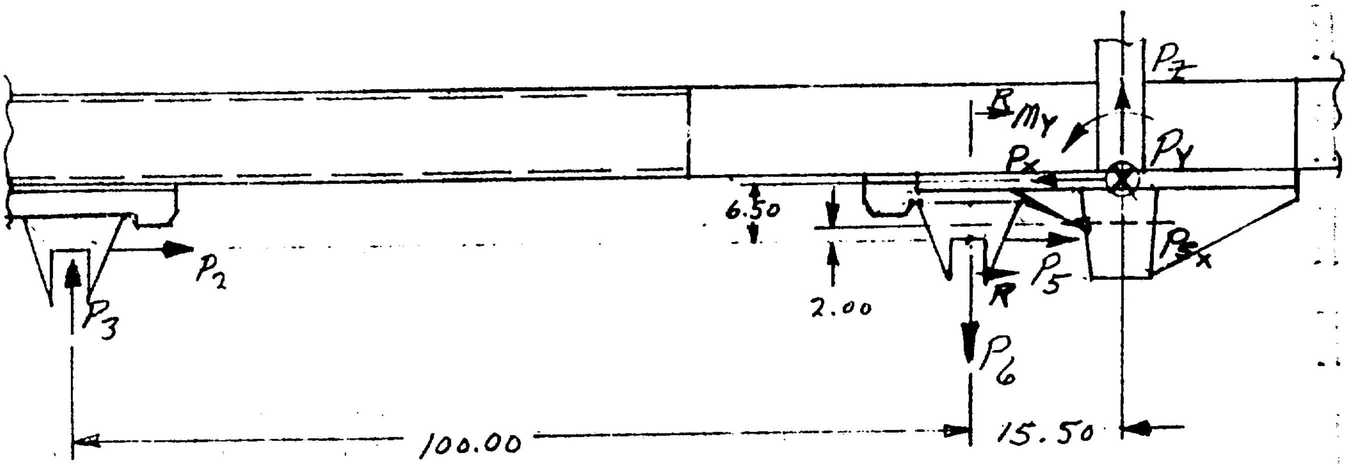
8/17/73

6K ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIGURATION





SOCKET & BEAM LOADS FROM PG. 2'.
ASSUME TIE DOWN REACTS ALL SHEAR LOADS
AND M_Y. REACTIONS TO P_Y CALCULATED
SEPARATELY.

$$P_5 \ \& \ P_2 = 0 \rightarrow (21{,}600 + 24800) = 0 \rightarrow 46{,}400 \ \#$$

$$P_3 = \frac{1{,}103{,}000 + 15.50\,(30{,}400 + 51{,}800) + 6.50 \times 21{,}600 + 2.00 \times 2\ldots}{100.00}$$

$$= 25{,}630 \ \#$$

$$P_6 = \frac{1{,}103{,}000 + 115.50\,(30{,}900 + 51{,}800) + 6.50 \times 21{,}600 + 2.00 \times 24{,}800}{100.00}$$

$$= 107{,}930 \ \#$$

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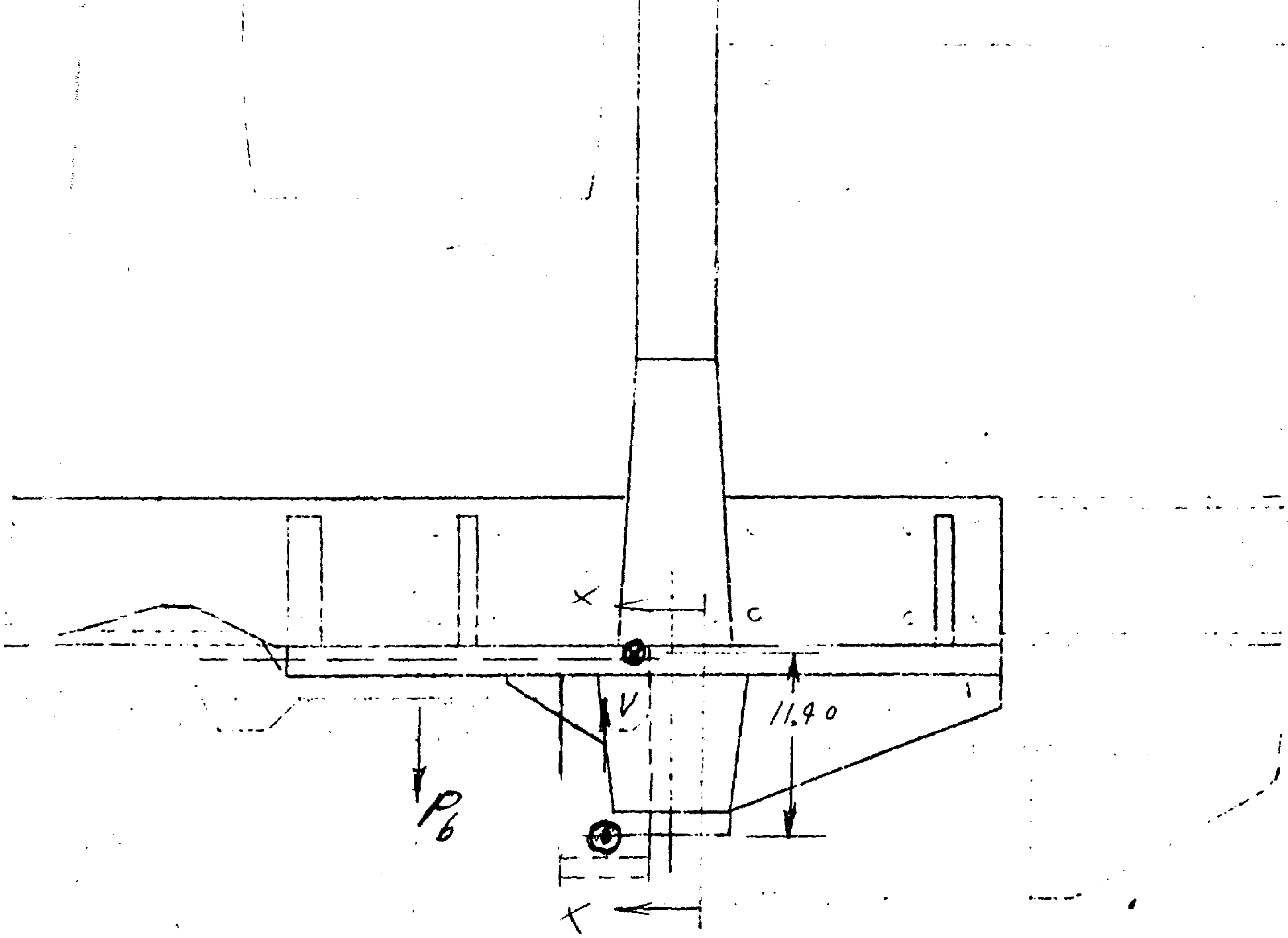
6 K ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG



$$V = \frac{11.40 \times 33{,}300}{34.00} = 11{,}200 \#$$

DUE TO V, $P_6 = \frac{115.5 \times 11{,}200}{100}$ 13,000 #

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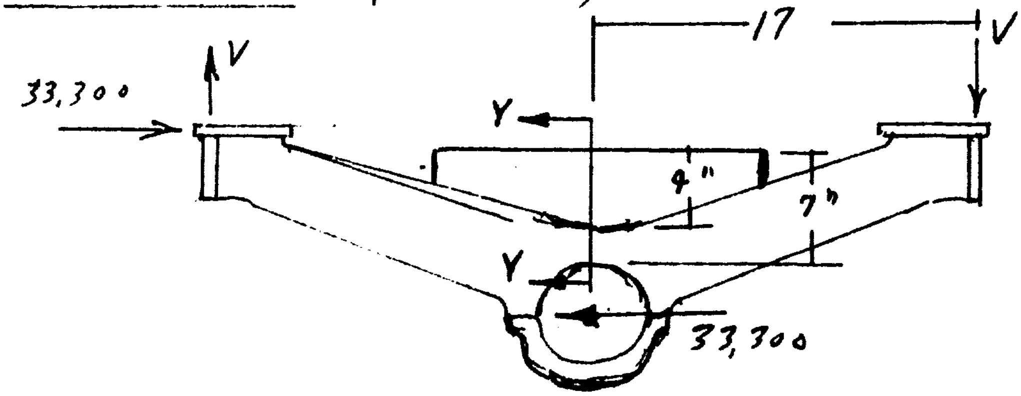
6K ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

VIEW X-X (PG 19a)



SECTION Y-Y

$V_{11} = 11,200$ # (PG. 19a)

$M_{YY} = 17 \times 11,200 = 190,000$ IN #

ADD 1" PLATE AT Y-Y TO MAKE TOTAL SECTION HEIGHT 7".

$f_b = \dfrac{6 \times 190,000}{1 \times 7^2} = 23,000$ PSI

$F_{TU} = 55,000$ PSI

$S.F. = \dfrac{55000}{23000} = \underline{2.40}$

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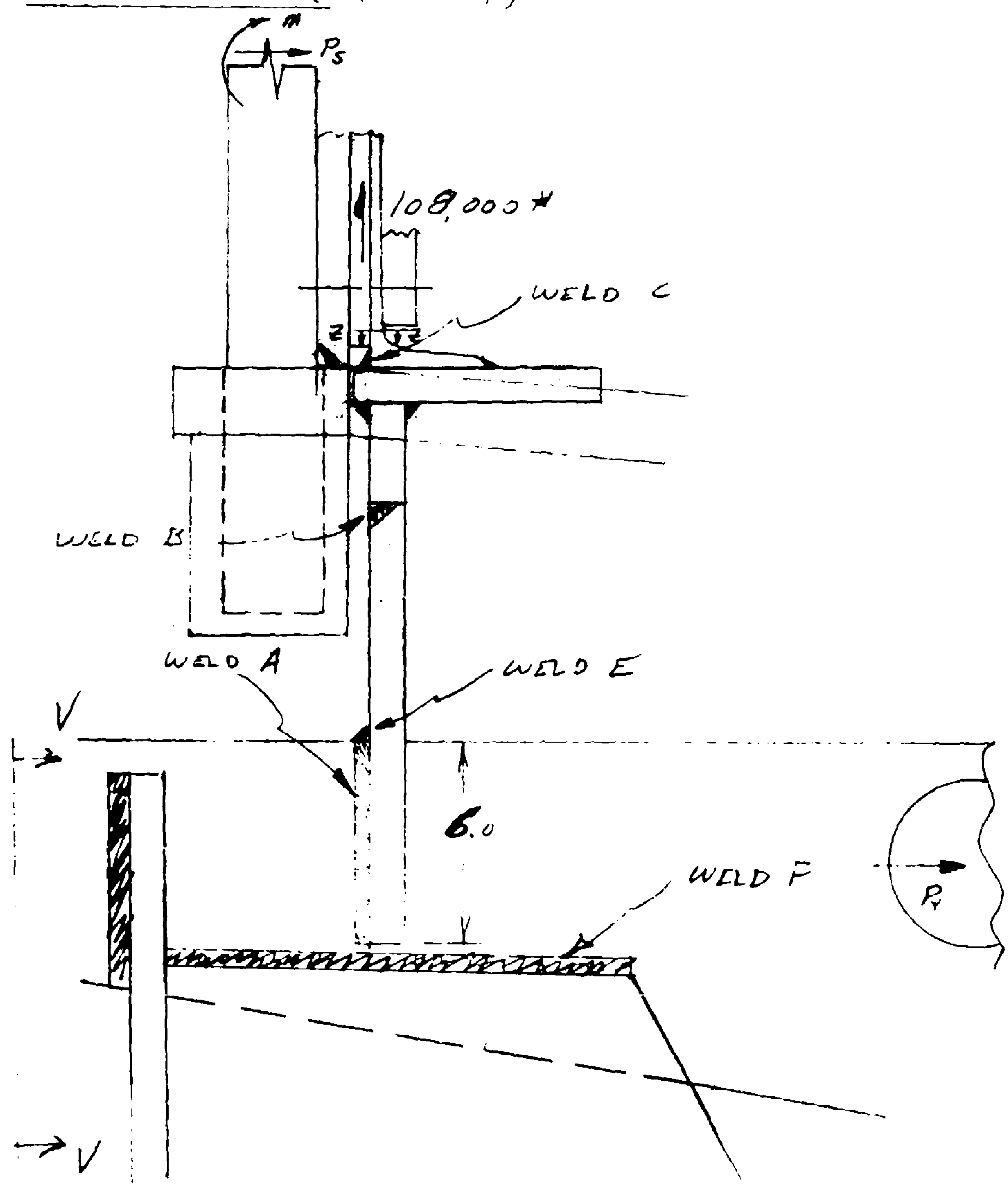
℄ RoPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

SECTION R-R (PG. 19)



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GK ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG

WELD A (PG. 20)

$$P_6 = 108,000 \ \#$$

WELD A: TWO 6 IN. LONG, $\frac{3}{4}$ IN. FILLET WELDS

$$A_s = 2 \times 6 \times .75 \times .707 = 6.3 \ IN^2$$

$$f_s = \frac{108,000}{6.3} = 17,000 \ PSI$$

$$F_{SU} = .6 \times 50,000 = 30,000 \ PSI$$

$$S.F. = \frac{30000}{17000} = 1.76$$

WELD B (PG. 20)

$$P_6 = 108,000 \ \# \quad P_5 = 46,400 \ \#$$

WELD B: 14.5 IN LONG, $\frac{1}{2}$ IN. GROOVE WELD.

$$A_T = \frac{1}{2} \times 14.5 = 7.2 \ IN^2$$

$$f_t = \frac{108,000}{7.2} = 15.000 \ PSI$$

$$f_s = \frac{46,400}{7.2} = 6,000 \ PSI$$

$$S.F. = \frac{50,000}{(15 + \frac{6}{2})10^3} = \underline{2.8}$$

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6K RUPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

WELD C (PG. 20)

WELD C: 18 IN LONG, $\frac{3}{8}$ IN. FILLET WELD

$A_T = 18.00 \times .375 \times .707 = 4.80 \text{ IN}^2$

$f_T = \frac{108,000}{4.8} = 23,000$ PSI

$F_T = 50,000$ PSI

$S.F. = \frac{50,000}{23,000} = \underline{2.20}$

WELD E (PG. 20)

$P_E = P_5 = 46,400\#$ (PG. 19)

WELD E: 4 IN. LONG $\frac{3}{4}$ IN. FILLET WELD

$A_S = 4.00 \times .75 \times .707 = 2.1 \text{ IN}^2$

$f_S = \frac{46,400}{2.1} = 22,000$ PSI

$F_{SU} = 30,000$ PSI

$S.F. = \frac{30,000}{22,000} = \underline{1.36}$

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5K KIPS - BOLT ON

WELD F (PG. 20)

$P_Y = 33,700$ # (P_{MAX}, PG. 2')

WELD F: 8 IN LONG, $\frac{1}{2}$ IN FILLET WELD

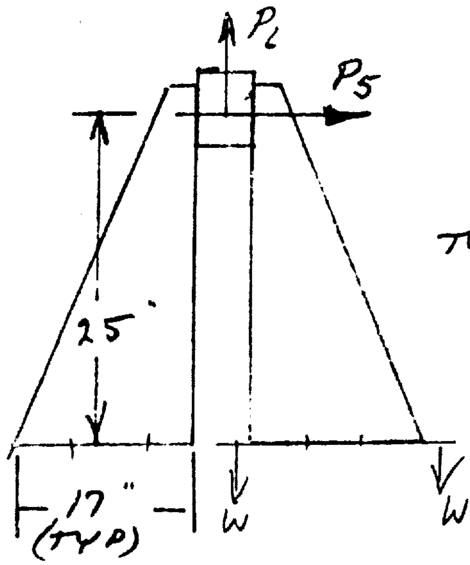
$A_S = 8.00 \times .50 \times .707 = 2.80\ IN^2$

$f_s = \frac{33,700}{2.80} = 12,000$ PSI

$F_{SU} = 30,000$ PSI

$S.F. = \frac{30000}{12000} = \underline{\underline{2.50}}$

VIEW V-V (PG 20)



SECTION W-W

$P_6 = 107,800$ # (PG. 19)
$P_5 = 46,400$ # (PG 19)

TWO $\frac{1}{2}$" FILLET WELDS AT W-W

$M = \frac{25 \times 46,400}{2} = 580,000$ "#

$f_t = \frac{107,800}{4 \times 17 \times .50 \times .707} = 5,000$ PSI

$f_b = \frac{6 \times 580,000}{1.00 \times 17^2 \times .707} = 17,000$ PSI

$F_{tu} = 50,000$ PSI

$S.F. = \frac{50,000}{5000 + 17000} = \underline{\underline{2.3}}$

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6K ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

WELD C : (PG. 20)

SIDE DEFLECTION OF THE ROPS DUE TO P_S & M (PG. 20) CAUSES IT TO BEAR AGAINST THE FRAME AND CAUSE BENDING AT SECTION Z-Z. FOLLOWING IS A CHECK OF WELD C FOR AN ULTIMATE BENDING MOMENT AT SECTION Z-Z.

FROM $F_{b_u} = \frac{Mc}{I}$,

$$M = \frac{F_{b_u} I}{c} \qquad F_{b_u} = 1.5 \times 70 = 105 \text{ KSI}$$

$$\text{FOR } t = .28'': \quad I = \frac{(.28)^3}{12} = .00183 \text{ IN}^4$$

$$c = \frac{t}{2} = .14 \text{ IN}$$

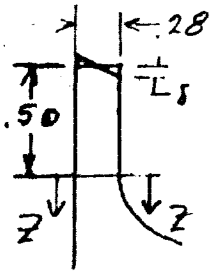
$$M = \frac{105000 \times .00183}{.14} = 1{,}370 \text{ IN\#/IN}$$

ASSUME $1\frac{1}{2}''$ COUPLE DISTANCE BETWEEN WELD LOAD AND BEARING LOAD.

$$P_{WELD} = \frac{1370}{1.50} = 900 \text{ \#/IN}$$

$$f_{T_{WELD}} = \frac{900}{.375 \times .707} = 3{,}400 \text{ PSI (NEG'L.)}$$

CHECK ELONGATION AT SECTION ZZ



ASSUME .50 IN LATERAL MOVEMENT AT TOP OF 9" FRAME. ROTATION = $\frac{.50}{9.00}$ = .056 RAD.
ASSUME .50 IN LONG BEAM EFFECTIVE AT SECT

$$\delta = c\theta = \frac{.28}{2} \times .056 = .0078 \text{ IN}$$

$$\text{ELONGATION} = \epsilon = \frac{.0078}{.50} = .0156 = 1.56\%$$

ALLOWABLE ELONGATION = 10% MIN. (.

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~~FRAME~~ ~~CHECK~~, AXLE MOUNT TEST CONFIG.

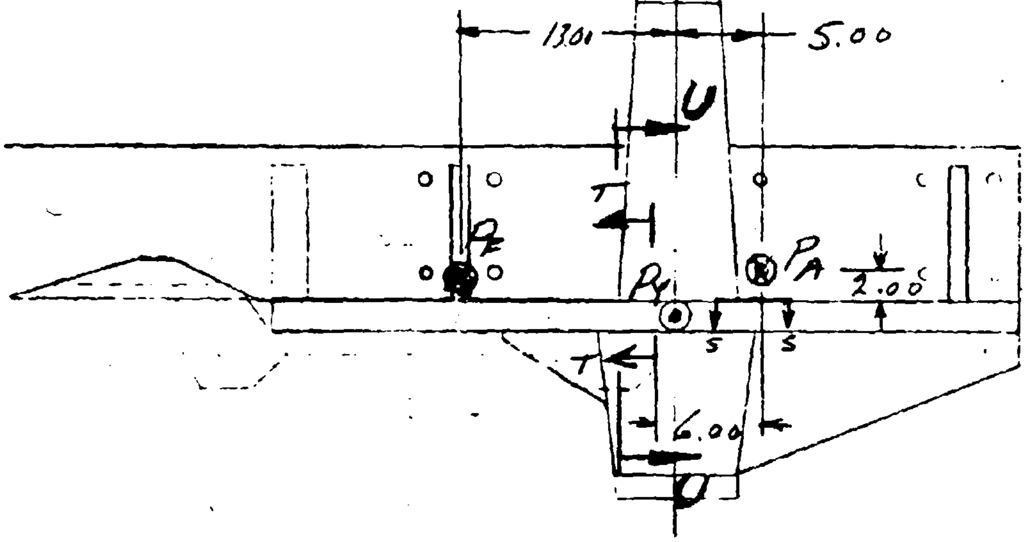
REACTIONS TO P_Y

ASSUMPTION 1: ASSUME 100% P_Y REACTED AT RIGHT SIDE. THIS PUTS ATTACH BOLTS IN TENSION.

P_Y = 33,300 # (PMAX, PG. 2')

P_F = 5.00 x 33,300 / 18.00 = 9,200 #

P_A = 33,300 − 9,200 = 24,100 #



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6K ROPS — BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG

SECTION S-S

$$P_A = 24{,}100\ \# \quad (PG\ 23)$$

$$M_{SS} = 2 \times 24{,}100 = 48{,}200\ \text{IN}\#$$

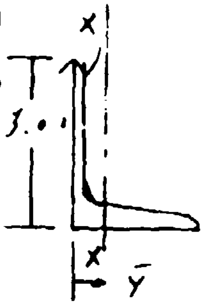
ASSUME 5" OF $\frac{3}{4}$" PLATE EFFECTIVE IN BENDING.

$$f_b = \frac{6 \times 48{,}200}{5 \times .75^2} = 100{,}000\ \text{PSI}$$

$$F_{b_U} = 1.5 \times 50{,}000 = 75{,}000\ \text{PSI}$$

S.F. < 1.00

SECTION T-T



CHECK OF CHANNEL FRAME BENDING DUE TO P_A.

$$M = 6.00 \times 24{,}100 = 145{,}000\ \text{IN}\#$$

$$f_b = \frac{145{,}000\ (2.485 - .69)}{.85} = 300{,}000\ \text{PSI}$$

$\bar{Y} = .69\ \text{IN}$

$I_{XX} = .85\ \text{IN}^4$

$$F_{b_U} = 1.5 \times 70{,}000 = 105{,}000\ \text{PSI}$$

S.F. < 1.00

P_Y IS NOT ABLE TO ENTER FRAME AT RIGHT SIDE.

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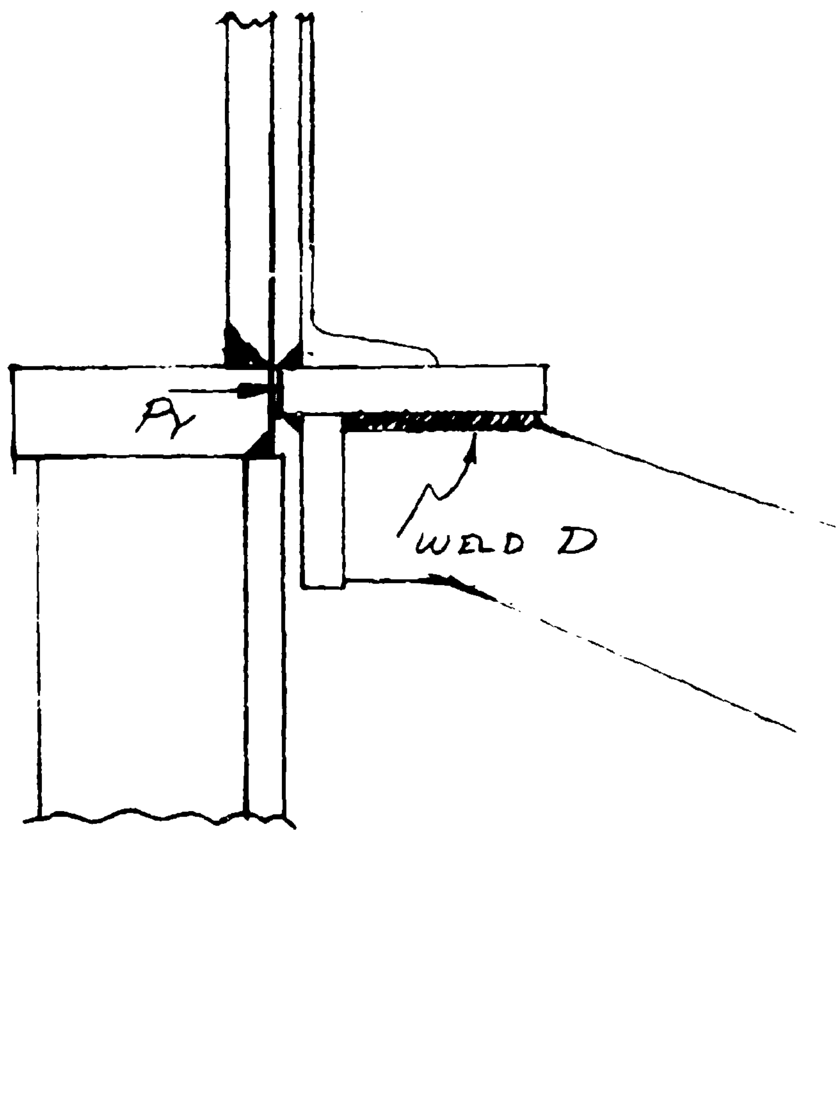
GK ROPS - BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

REACTIONS TO P_Y ASSUMPTION 2:

ASSUME 100% OF P_Y REACTED AT LEFT SIDE.

SECTION U-U (PG. 23)



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6K ROPS – BOLT ON

FRAME CHECK, AXLE MOUNT TEST CONFIG.

ASSUMPTION 2a: ASSUME P_Y LOADS FRAME THROUGH BEARING ON 1" PLATE AS SHOWN ON PG. 25.

WELD D (PG. 25)

P_Y = 33,300 # (PG. 23)

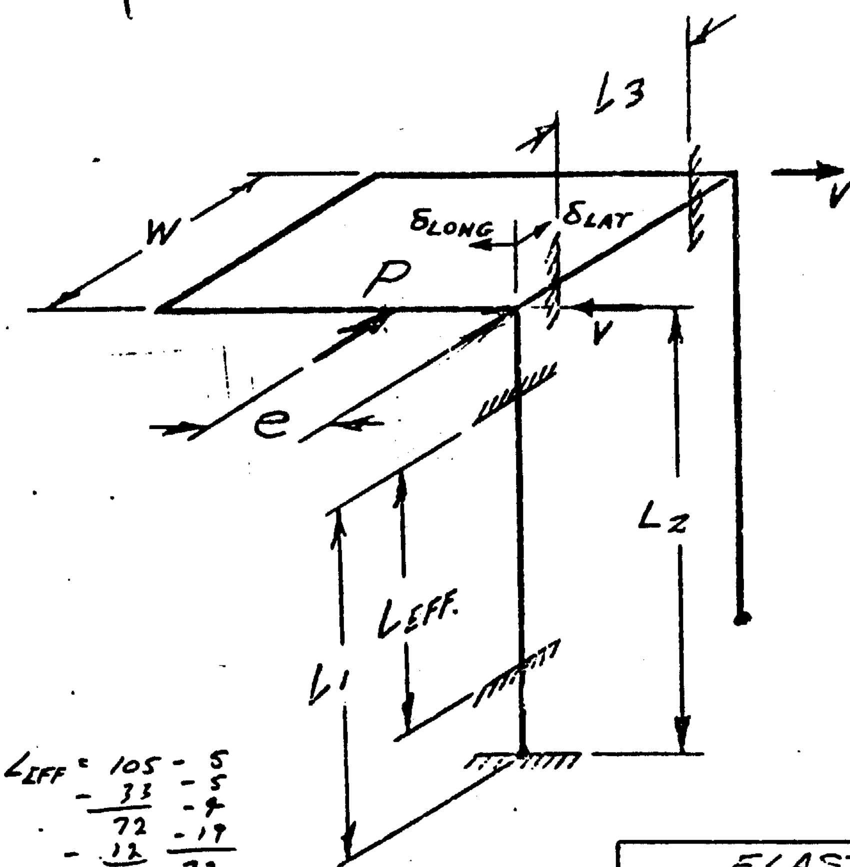
WELD D: TWO 5 IN. LONG, $\frac{1}{2}$ IN. FILLET WELDS.

A_s = 5.00 x .50 x .707 = 1.70 IN^2

$f_s = \frac{33,300}{1.70}$ = 20,000 PSI

F_{su} = 30,000 PSI   S.F. = $\frac{30000}{20000}$ = 1.50

ROPS LOAD VS. DEFLECTION CALCULATION



$L_{EFF} = 105 - 33 = 72 - 12 = 60$

$5 - 5 - 4 - 19 = 33$

L_{EFF} = LENGTH FROM POST FOOT TANGENT TO 1" INTO UPPER GUSSET.

L_1 = DISTANCE FROM TOP OF SOCKET TO 5" INTO UPPER GUSSETT.

L_2 = DISTANCE FROM TOP OF SOCKET TO UPPER STRUCTURE ℄.

L_3 = LENGTH 5" INTO GUSSET ON EACH SIDE.

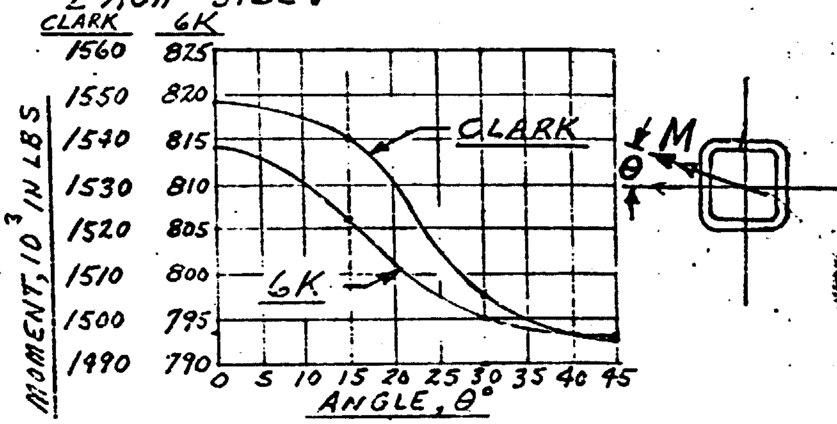


FIG. I ULT. BEND MOMENT CAPABILITY VS. MOMENT ANGLE

F_{TU} = 77,400 PSI

										10^6 IN LB/IN			ELASTIC CURVE					ULTIMATE CAPABILITY					
														$\frac{PL_1^3}{6EI}$	$\frac{L_2}{\frac{W}{2}}\cdot\frac{(\frac{L}{2})^3}{3EI}$	$\frac{V_E L_2^3}{3EI}$	$\delta_{LAT_1} + \delta_{LAT_2} + \frac{e}{\frac{W}{2}}\cdot(\delta_{LONG})$		$\frac{P}{2}\cdot\frac{L_{EFF}}{2}$	$V_U\cdot\frac{L_{EFF}}{2}$	$M_{LAT} \to M_{LONG}$		$\frac{M_{FIG.1}}{COEF.P}$
VEHICLE	SIZE	I	J	V_{ER}	L_1	L_2	L_3	W	e	K_{TOR}	K_{BE}	K_{BU}	V_E	δ_{LAT_1}	δ_{LAT_2}	δ_{LONG}	$\Sigma\,\delta$, IN.	V_U	M_{LAT}	M_{LONG}	M	θ	P, LB.
CLARK	5×6×½	13.3	33.[illegible]	[illegible]5.5	49	61	46	72	14.3	.83	1.33	~~[illegible]~~ 25	.122 P	.0000140 P	.0000042 P	.0000066 P	.0000208 P	.176 P	9.12 P	3.21 P	9.70 P	19°	158,000
6K	5×5×⅜	21.4	30.2	155	85	92.5	27	43	36	.44	.10	.76	.155 P	.000161 P	.00019 P	.000064 P	.00029 P	.530 P	18.90 P	20.06 P	27.5 P	43°	28,900
K	"			60								1.52						.65 P	15.0 P	19.50 P	24.6 P	38°	32,200

$$K_{TOR} = \frac{1}{\delta} = \frac{1\,IN\,LB}{R\frac{TL}{JG}} = \frac{1\,IN\,LB}{\frac{W}{2}\cdot\frac{1}{2}\cdot\frac{L_2}{JG}}$$

$$K_{BE} = \frac{1}{\delta} = \frac{1\,IN\,LB}{\frac{1}{W}\cdot\frac{L_2^3}{3EI}}$$

$$K_{BU} = \frac{1}{\delta} = \frac{1\,IN\,LB}{\frac{1}{W}\cdot\frac{L_{EFF}^3}{12EI}}$$

$$V_E = \frac{K_{BE}}{K_{BE}+K_{TOR}}\left(\frac{Pe}{W}\right) \qquad V_U = \frac{K_{BU}}{K_{BU}+K_{TOR}}\left(\frac{Pe}{W}\right) \qquad P_S = \frac{P}{2}\cdot\frac{L_2}{\frac{W}{2}}$$

FOR $F_{TU} = 77.4$ KSI $P = 32,200$ #

$$P_{MAX} = \frac{80}{77.4} \times 32,200 = \underline{33,300 \; \#}$$

$P_X = V_U = .65P = .65 \times 33,300 = 21,600$ #

$P_Y = .5P =$ 16,650 #

$P_Z = \frac{39.3}{21.5} \times 16,650 =$ 30,400 #

$M_X = 15.0 \times 33,300 =$ 500,000 IN#

$M_Y = 19.50 \times 33,300 =$ 650,000 IN#

$M_Z = \frac{.44}{.44 + 1.52} \cdot \frac{33,300 \times 36}{2} =$ 135,000 IN#

1.96

IN SOCKET

$P_X = 21,600$ #

$P_Y = 16,650$ #

$P_Z = 30,400$ #

$M_X = 500,000 + \overset{350,000}{(21.00 \times 16,650)} = 850,000$ IN#

$M_Y = 650,000 + \overset{453,000}{(21.00 \times 21,600)} = 1,103,000$ IN#

$M_Z = 135,000$ IN#

IN BEAM $(M_Z = 335,000$ IN#, PG. 4')

$$P_{S_Z} = \frac{850,000 + (4 \times 30,400) - (5.50 \times 16,650)}{17.00}$$

$= 51,800$ #

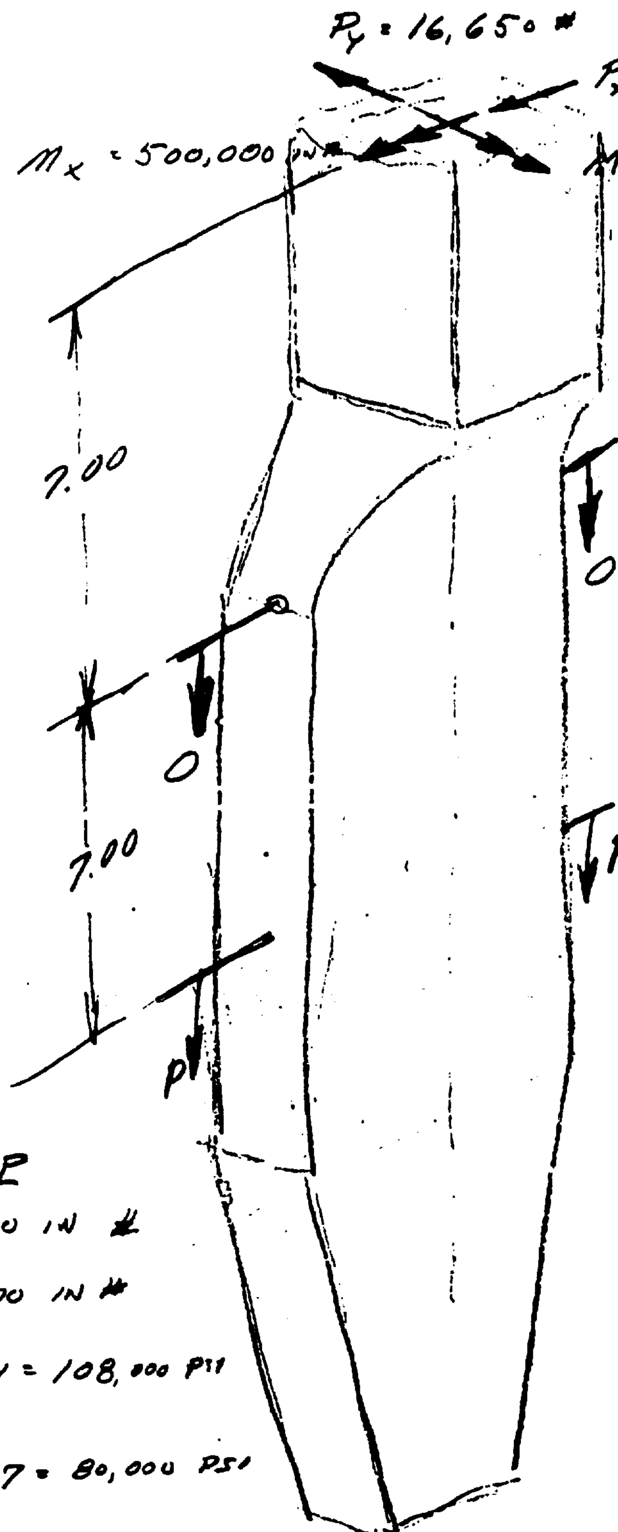
$$P_{S_X} = \frac{335000 + (4.00 \times 21,600)}{17.00} = 24,800 \; \#$$

$P_{FRAME_Y} = P_Y = 16,650$ #

$P_{FRAME_X} = P_X + P_{S_X} = 21,600 + 13,000 = 34,600$ #

$P_{FRAME_Z} = P_Z + P_{S_Z} = 30,400 + 51800 = 82,200$ #

$M_{FRAME_Y} = 1,103,000 - (5.50 \times 21600) = 984,000$ IN#



SECTION O-O

$M_X = 500,000 + 7.00\,(16,650) \quad (117,000)$

$= 617,000$ IN #

$M_Y = 650,000 + 7.00\,(21,600) \quad (151,000)$

$= 801,000$ IN #

5.00 — 2.85 — X — Y

$f_{b_X} = \dfrac{6 \times 617,000}{5 \times \overline{2.85}^2} = 91,000$ PSI

$f_{b_Y} = \dfrac{6 \times 801,000}{2.85 \times \overline{5.00}^2} = 67,000$ PSI

$\Sigma f_b = 158$ KSI

$F_{bu} = 1.47 \times 125,000 = 183,000$ PSI

$S.F. = \dfrac{183}{158} = 1.16$

SECTION P-P

$M_X = 734,000$ IN #

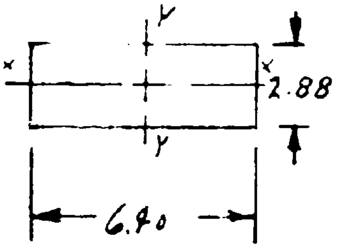
$M_Y = 952,000$ IN #

$f_{b_X} = \dfrac{734}{617} \times 91 = 108,000$ PSI

$f_{b_Y} = \dfrac{952}{801} \times 67 = 80,000$ PSI

$\Sigma f_b = 188,000$ PSI

SECTION A-A



$A = 18.4 \text{ IN}^2$
$I_{XX} = 12.7 \text{ IN}^4$
$I_{YY} = 63 \text{ IN}^4$

$M_{XX} = 850,000 \text{ IN \#}$

$M_{YY} = 1,103,000 \text{ IN \#}$

$$f_{b_{XX}} = \frac{850,000 \times 1.44}{12.7} = 96,400 \text{ PSI}$$

$$f_{b_{YY}} = \frac{1,103,000 \times 3.20}{63} = 56,000 \text{ PSI}$$

$\Sigma f_b = 152,400 \text{ PSI}$

$F_{b_U} = 1.47 \times 125,000 = 183,000 \text{ PSI}$

$$S.F. = \frac{183,000}{152,400} = \underline{\underline{1.20}}$$

SOCKET LOADS

DUE TO P_X, $P_3 =$ 21,600 #

DUE TO P_Y, $P_1 =$ 16,650 #

DUE TO P_Z, $P_N = \frac{30,400}{\sin 7° \times 2}$ = 125,000 #

DUE TO M_X, $P_1 = \frac{850,000}{8.75}$ = 97,200 #
P_2 = 97,200 #

DUE TO M_Y, $P_3 = \frac{1,103,000}{8.75}$ = 126,000 #
P_4 = 126,000 #

$$M_Z = 135,000 + 2.90\overbrace{(16,650+97,200)}^{330,000} - 1.80\underbrace{(97,200)}_{-175,000} + 2.10\underbrace{(21,600)}_{45,300} = 335,000 \text{ IN}\#$$

ASSUMING M_Z REACTED BY P_2 & P_5,
$P_2 = \frac{335,000}{3.6}$ = 93,000 #
P_5 = 93,000 #

SUMMING LOADS:

$P_1 = 16,650 + 97,200$ = 113,850 #
$P_2 = 97,200 + 93,000$ = 190,200 #
$P_3 = 21,600 + 126,000$ = 147,600 #
$P_4 =$ 126,000 #
$P_5 =$ 93,000 #
$P_6 =$ 0 #

SOCKET LOADS

ASSUMING M_Z REACTED BY P_4 & P_6,

$$P_4 = \frac{335000}{2.25} = 149{,}000\ \#$$
$$P_6 = 149{,}000\ \#$$

SUMMING LOADS.

$$P_1 = 16{,}650 + 97{,}200 = 113{,}850\ \#$$
$$P_2 = 97{,}200\ \#$$
$$P_3 = 21{,}600 + 126{,}000 = 147{,}600\ \#$$
$$P_4 = 126{,}000 + 149{,}000 = 275{,}000\ \#$$
$$P_5 = 0\ \#$$
$$P_6 = 149{,}000\ \#$$

SECTION M-M

$$P_4 = 275{,}000\ \#$$

$$A_S = 5 \times 1.50 = 7.50\ \text{IN}^2$$

$$f_S = \frac{275000}{7.50} = 37{,}000\ \text{PSI}$$

$$F_{SU} = 45{,}000\ \text{PSI}$$

$$S.F._U = \frac{45000}{37000} = 1.22$$

UPPER CROSS BEAM LOADS

$P_1 = 113,850$ #

$q = \dfrac{113,850+113,850}{35.00} = 6500$ #/IN

$P_{S_{UP.}} = \dfrac{(4.50-.38)\times 113,850}{35.00} = 13,400$ #

SECTION B-B

$P_1 = 113,850$ #

$M = .40 \times 113850 = 45,500$ IN#

$f_b = \dfrac{6\times 45,500}{2\times 2.00^2} = 34,000$ PSI

$F_{bY} = 1.28 \times 38,000 = 48,000$ PSI

$S.F._Y = \dfrac{48000}{34000} = \underline{1.41}$

$A_S = 4.65$ IN^2

$f_S = \dfrac{113,850}{4.65} = 24,500$ PSI

$F_{S_U} = 45,000$ PSI

$S.F._U = \dfrac{45000}{24500} = \underline{1.84}$

ROLLOVER

$P = \dfrac{844,000}{15} \times \dfrac{80}{97.4} = 56,100$ #

$P_1 = \dfrac{56,100}{33,300} \times 113,850 = 192,000$ #

$A_S = (2.00 \times 2.00) + (1.5 \times 1.5\ TAN\ 30° \times \frac{1}{2}) = 4.65\ IN^2$

$f_S = 192,000 / 4.65 = 41,000$ PSI $\quad SF = \frac{45}{41} = 1.10$

SECTION O-O (PG. 1)

$$P_{S_Z} = 51,800 \ \#$$

$$A_S \text{ (WEB)} = .75 \times 3.00 = 2.25 \text{ IN}^2$$

$$f_S = \frac{51,800}{2.25} = 23,000 \text{ PSI}$$

$$F_{S_U} = 45,000 \text{ PSI}$$

$$MS_U = \frac{45000}{23000} = \underline{1.96}$$

SECTION D-D

$$P_{S_Z} = 51,800 \text{ \#}$$
$$P_{S_X} = 24,800 \text{ \#}$$
} PG. 2'

$$q = \frac{113,850}{93,500} \times 5340 = 6500 \text{ \#/IN}$$

$$P_T = 6.00 \times 6500 = 39,000 \text{ \#}$$

$$M = 6.00 \times 24,800 = 149,000 \text{ IN\#}$$

$$f_T = \frac{39000}{5 \times 1.5} = 5200 \text{ PSI}$$

$$f_b = \frac{6 \times 149,000}{1.5 \times 5.0^2} = 24,000 \text{ PSI}$$

$$F_{TY} = 38,000 \text{ PSI}$$

$$S.F. = \frac{38000}{24,000 + 5200} = \underline{1.30}$$

SECTION E-E

$$P_2 = 190,200 \text{ \#}$$
$$P_5 = 93,000 \text{ \#}$$
$$M_Z = 335,000 \text{ IN\#}$$
} PG. 4'

$$P_T = P_2 - P_5 = 190,200 - 93,000 = 97,200 \text{ \#}$$

$$f_T = \frac{97,200}{7.5 \times 1.5} = 8,700 \text{ PSI}$$

$$f_b = \frac{6 \times 335,000}{1.5 \times 7.5^2} = 23,800 \text{ PSI}$$

$$F_{TY} = 38,000 \text{ PSI}$$

$$S.F._Y = \frac{38000}{8,700 + 23,800} = \underline{1.17}$$

STUD ANALYSIS, $1\frac{1}{4}$ - 7UNC THD

$$P_{STUD} = P_Z + \frac{2\ M_Y}{8.75}\ \mathrm{TAN}\ 7^\circ$$

$$= 30{,}400 + \frac{2 \times 1{,}103{,}000}{8.75}\ \mathrm{TAN}\ 7^\circ = 61{,}400\ \#$$

31,000

$A_{TENS} = .968\ \mathrm{IN}^2$ (ESHBACH, PG 1-202)

$$f_T = \frac{61{,}400}{.968} = 64{,}000\ \mathrm{PSI}$$

$$A_S = \frac{\pi D L}{2} = \frac{\pi \times 1.15 \times 1.25}{2} = 2.25\ \mathrm{IN}^2$$

$$f_S = \frac{61{,}400}{2.25} = 27{,}300\ \mathrm{PSI}$$

$F_{TU} = 125{,}000\ \mathrm{PSI}$

$F_{SU} = 80{,}000\ \mathrm{PSI}$

STUD CRITICAL IN TENSION

$$S.F._U = \frac{125{,}000}{64{,}000} = \underline{\underline{1.95}}$$

$$P_{STUD} = P_Z + (P_3 + P_4 + P_6)\ \mathrm{TAN}\ 7^\circ$$

571,000

$$= 30{,}000 + (147{,}600 + 275{,}000 + 149{,}000)\ \mathrm{TAN}\ 7^\circ$$

$$= 100{,}000\ \#$$

$$f_t = \frac{100{,}000}{.968} = 104{,}000\ \mathrm{PSI}$$

$$A_S = \frac{\pi \times 1.15 \times .58}{2} = 1.05$$

$$f_S = \frac{100{,}000}{.105} = \underline{96{,}000\ \mathrm{PSI}} \quad F_{SU} = .64 \times 150{,}000 = \underline{96{,}000}$$

APPENDIX 6.6

CERTIFICATION TEST RESULTS

LOCKHEED PROPULSION COMPANY

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

REDLANDS CALIFORNIA

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

TEST REPORT TR-684-065

CONFORMANCE TESTING ON A ROLL-OVER
PROTECTIVE STRUCTURE FOR THE
U. S. ARMY 6K
ROUGH TERRAIN FORKLIFT

The Roll-Over Protective Structure, Part Number 299279, described herein has been tested in accordance with the applicable sections of the SAE Recommended Practice J-394a and met the required criteria.

Test Completion Date - 28 August 1973

Prepared by: H. C. Davis, Test Engineer

Approved by: T. P. Carpenter, Mgr., Test Department

State of California)
County of San Bernardino) ss

W. Dubyk, Director, Product Assurance Branch, being duly sworn, deposes and says: That the information contained in this report is the result of carefully conducted tests and is to the best of his knowledge true and correct in all respects.

Subscribed and sworn before me on this 7th day of January 1974.

OFFICIAL SEAL
J. BETH BARNES
NOTARY PUBLIC-CALIFORNIA
PRINCIPAL OFFICE IN
SAN BERNARDINO COUNTY
My Commission Expires June 28, 1974

J. Beth Barnes

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

VEHICLE MANUFACTURER Chrysler

VEHICLE TYPE/MODEL 6K Forklift VEHICLE WEIGHT 23,500

ROPS MANUFACTURER Tubelok ROPS SERIAL NUMBER NA

ROPS PART NUMBER 299024 ROPS MATERIAL ---

TEST DATE 28 August 1973 TEST TEMPERATURE 76°F

CUSTOMER ORDER NUMBER 684 LPC WORK ORDER T7162

[X] FOPS TEST PER SAE J-231

[X] HORIZONTAL LOAD TEST PER SAE J-394a PARAGRAPH 5.1

[X] VERTICAL LOAD TEST PER SAE J-394a PARAGRAPH 5.2

[X] CRITICAL ZONE PER SAE J397a

[ ] IMPACT TEST - LOAD ____ DURATION ____

[ ] OTHER ____

TEST RESULTS/CONCLUSIONS:

The ROPS was subjected to a FOPS test and horizontal and vertical loads in accordance with SAE Recommended Practices J-231 and J-394a. The ROPS met or exceeded the SAE requirements.

DISCUSSION

The ROPS was mounted to the 6K forklift in accordance with LPC Drawing 299279.

The chassis was mounted in the test bay in accordance with SAE Recommended Practice J-394a. The tiedown arrangement is shown in Drawing 299500.

FOPS

A solid wooden form representing the critical zone was installed in the ROPS to aid in the final determination of success or failure. The critical zone was installed per SAE J-397a and LPC Drawing 299500. The test setup is shown in Figure 1.

The FOPS test made use of high speed movies to ensure that the critical zone was not violated during the FOPS test. Deflection

Prepared by: ____ Approved by: ____

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

TEST RESULTS/CONCLUSIONS: (Continued)

of the ROPS was measured by a photo target grid that was mounted beyond the ROPS in view of the camera.

A 500-pound standard drop object was positioned over the ROPS, raised 17 feet and dropped. There was no violation of the critical zone. The roof structure after impact is shown in Figure 2.

HORIZONTAL LOADING

A load application system consisting of one 700,000-pound hydraulic ram was installed to contact the ROPS roof for horizontal loading in accordance with Drawing 299500.

The test operations procedure is presented on pages 5 through 8.

One fourteen-inch linear potentiometer was utilized to measure deflection at the point of load application.

The force and deflection measurements were displayed in digital format for monitoring during the test and were also recorded at each deflection increment.

The digital data were entered manually into a Hewlett Packard desk top computer where each channel was converted to engineering units and the total energy, "U" was calculated and accumulated for each increment of horizontal load application. This data is presented in Table 2.

A plot of load versus deflection was also generated automatically by the computer during the test (page 11).

A total of 20 strain measurements were recorded during the horizontal loading to monitor the ROPS deformation. The strain gage locations are shown on Drawing 299500. The strain gage data are presented in Addendum I.

Steel scales and dial indicators were installed on the ROPS to measure deflection. These readings are presented in Table 1. The locations are shown on Drawing 299500.

The load was applied, as required, to product approximate one-half inch deflection increments during the horizontal loading. At 5.5

Prepared by: ____________ Approved by: ____________

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DESCRIPTION

TEST RESULTS/CONCLUSIONS: (Continued)

inches deflection, the minimum force requirement was met. At 10.0 inches, the minimum energy requirement was met and the horizontal load test was terminated.

At full deflection, Figure 3, the critical zone was not violated.

VERTICAL LOAD

The load column was aligned to the geometric center of the ROPS with a load pad to distribute the load over the full surface of the ROPS.

The incremental load and deflection were recorded during the vertical loading. Strain gage data were also recorded and are presented in Addendum II.

Optical deflection measurements were made using steel scales and are presented on page 12.

The vertical load setup is shown in Figure 4.

The critical zone was not violated during the vertical load test.

Prepared by: [signature] Approved by: [signature]

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
EQUIPMENT LIST

Hydraulic Ram (Horizontal)	700K, Pickens Inc. 9480-18-3683 18-inch stroke
Hydraulic Ram (Vertical)	300K, Rodgers Hydraulic, Part Number 1-150 BR-7½, 7½-inch stroke
Load Cell (Horizontal)	Ormond L-25-50K-557
Load Cell (Vertical)	Ormond L-25-50K-557
Displacement Transducers	1 each 14-inch, 3 each Starrett Dial Indicators and 3 each 18-inch scales, and 1 Bourns 2001081615 potentiometers
Data Acquisition System	Beckman 210, 84-channel Digital Data System

OPTIONAL EQUIPMENT

Strain Gages	BLH FAP-12-12 or equivalent
Thermocouple Potentiometer	
Conditioning Box Controller	

MEASUREMENT ACCURACY

The measurement systems and devices utilized in support of this test program are periodically maintained and calibrated to assure the following steady state accuracies. Instrument calibrations are traceable to the National Bureau of Standards.

Force	± 1 percent
Displacement	∓ 2 percent
Temperature	∓ 5 °F

TEST OPERATIONS	INSPECTION

3.0 TEST OPERATIONS

3.1 Preliminary Preparations

3.1.1 Install chassis reinforcements per assembly drawing 299279 (Certified welder required.) 8/2/73 9314

3.1.2 Install 20 post yield strain gages as shown on 299500. 1585

3.1.3 Install the vehicle chassis in the test bay by welding per drawing 299501. 8/27/73

3.1.4 Install the ROPS 299024 into the socket mounts 299239 and torque the eye bolts to 500±40 foot-pounds. 8/27/73

3.1.5 Paint the assembly as required. Colors: chassis - olive drab; ROPS - yellow; tie-down fixtures - gray. N.P.

3.1.6 Install the critical zone per SAE J-397A and drawing 299500

3.1.7 Prepare 1 2' x 8' photo targets by carefully applying 1" black tape to a white background as shown in Figure 1.

3.2 FOPS TEST

3.2.1 Attach the 500-pound drop weight to a mobile crane using an electrically operated bomb release.

3.2.2 Conduct sufficient practice drops on clear ground to ensure reliable release and good vertical attitude at the proposed impact point.

3.2.3 Position the drop weight at the center of the ROPS section covered with wire mesh.

3.2.4 Set up documentary movie cameras to record the drop sequence.

TEST OPERATIONS	INSPECTION	CUSTOMER APP

3.0 TEST OPERATIONS (Continued)

3.2.5 Install one photo target horizontally on the wall behind the critical zone to record the dynamic deflection of the steel mesh.

3.2.6 Install a 1" diameter x 6" long probe (approximate dimensions) extending downward under the drop point to be viewed by the high speed camera. Attach with wire, do not weld.

3.2.7 Position the 200 pps movie camera viewing the target grid at the same level as the critical zone top.

3.2.8 Raise the weight 17 feet above the ROPS roof and conduct the ROPS test per SAE J-231.

3.2.9 Ensure the critical zone has not been violated. Take post test photographs per test engineer direction.

3.2.10 If the deformed wire mesh is too close to the critical zone to conduct the horizontal load test, restore it to the original minimum level. 3 1/4 De...

3.3 Horizontal Load Test

3.3.1 Ensure load column center line is contacting the ROPS roof at the exact distance from the vertical supports as shown on drawing 299500 and is in a level attitude. The load distribution plate must span 20 inches minimum along the ROPS top and it must be free to rotate horizontally as load is applied.

3.3.2 Install precision scales for optical deflection measurements in accordance with drawing 299500 and position the surveyor's transits for viewing.

3.3.3 Install dial gages in accordance with drawing

3.0 TEST OPERATIONS (Continued)

Step	Operation	TEST OPERATIONS	INSPECTION	CUSTOMER APPROVAL
3.3.4	Calibrate all instrumentation and prepare for recording all data.	8/28/73 1565		
3.3.5	Take prefire photographs of the ROPS and test setup.	4276	8/28/73	
3.3.6	DELETE			
3.3.7	Apply load to achieve incremental deflections of 0.5 inches and conduct the side loading in accordance with SAE J-394A.		8/28/73	
3.3.8	Record the dial gages and optical scales at each inch of deflection.		8/28/73	
3.3.9	At each deflection step, calculate total energy.	8/28/73 1565		
3.3.10	Continue loading until both the minimum load and minimum energy have been achieved.		8/28/73	
3.3.11	While at full load, ensure the critical zone has not been violated.		8/28/73	

NOTE

IF BOTH CONDITIONS OF LOAD AND ENERGY CANNOT BE SATISFIED, CONSULT THE TEST ENGINEER.

SAFETY NOTE

USE EXTREME CAUTION IN APPROACHING FULLY LOADED ASSEMBLY. A VIOLENT STRUCTURAL FAILURE COULD OCCUR AT ANY TIME.

3.0 TEST OPERATIONS (Continued)

Step	Operation	TEST OPERATIONS	INSPECTION	CUSTOMER APPROVAL
3.3.12	Take documentary photographs per test engineer direction.			
3.3.13	Remove the side load and record the post test measurements on all channels.	[illegible] 1565		
3.3.14	Take post test photographs per test engineer direction.			
3.4	Vertical Load Test			
3.4.1	Ensure load column is aligned to the center of the ROPS roof.	8/28/75 [illegible]		
3.4.2	Ensure data acquisition for digital display and strain gage recording is ready for test.	[illegible] 156		
3.4.3	DELETE			
3.4.4	Apply load increments of 10K, 16K, 21K, 22K, 23K, and full load of 23.5K in accordance with SAE J-394A, paragraph 5.2. Record all specified data channels and optical deflection measurements at each load increment.	8/28/75 [illegible]		
3.4.5	While at full load, verify that the critical zone has not been violated.	8/28/75 [illegible]		
3.4.6	Take documentary photographs per test engineer direction.	[illegible] 8-28-73		

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K FORKLIFT – HORIZ LOAD TEST DATE 8/28/73

DEFL	LOAD	ENERGY	1-D	2-D	3-D	4-D	1-S	2-S	3-S	4-S			COMMENTS
ZERO	ZERO	ZERO	0.00	0.00	0.00	0.00	1.00	1.00	2.00	2.00			1-D – 2.5"
1.00	1797	886	.046	.065	.995	.993	2.10	[illegible]	1.60	2.41			2D – 6.5"
2.02	3995	3731	.099	.135	.991	.980	3.45	1.75	1.25	2.98			
3.00	6682	8806	.113	.161	.986	.978	4.26	2.12	0.77	3.45			NEW ZERO OF
4.00	10275	17250	.121	.179	.970	.951	6.15	2.50	0.04	3.80			4" DEFL
5.00	13346	29095	.123	.190	.926	.892	7.40	2.60	6.01	9.76			3-S = 7.00
6.00	16242	43907	.128	.204	.984	.839	8.72	2.90	5.10	9.91			4-S = 9.62
7.00	18998	61539	.137	.223	.865	.804	10.00	3.25	4.25	10.07			
8.00	21441	81725	.148	.245	.832	.776	11.35	3.60	3.35	10.20			
9.03	23639	104875	.162	.270	.817	.752	12.65	3.90	2.53	10.42			
10.00	25385	128687	.176	.292	.806	.745	13.90	4.20	1.75	10.45			
3.48	ZERO	ZERO	.121	.167	.895	.864	5.15	2.10	6.56	8.56			

Prepared by: [stamp] 8/29/73 Approved by: [signature]

Page 1 of 1

TABLE I

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K Forklift Prototype TEST DATE 8-28-73

HORIZONTAL LOAD TEST PER SAE J-394a

REQUIRED ENERGY, U, POUND-INCHES, 122,204

REQUIRED MINIMUM HORIZONTAL LOAD 15,031 POUNDS

TEST STEP	△ NOMINAL	△ ACTUAL	HORIZONTAL LOAD APPLIED	CALCULATED ENERGY, U
1	0.5	.51	890	228
2	1.0	1.00	1,797	886
3	1.5	1.52	2,704	2,056
4	2.0	2.02	3,995	3,731
5	2.5	2.51	5,042	5,934
6	3.0	3.00	6,682	8,806
7	3.5	3.50	8,409	12,579
8	4.0	4.00	10,275	17,250
9	4.5	4.50	11,880	22,789
10	5.0	5.00	13,346	29,095
11	5.5	5.50	14,829	36,139
12	6.0	6.00	16,242	43,907
13	6.5	6.52	17,707	52,776
14	7.0	7.00	18,998	61,539
15	7.5	7.53	20,219	71,883
16	8.0	8.00	21,441	81,725
17	8.5	8.50	22,487	92,652
18	9.0	9.03	23,639	104,875
19	9.5	9.50	24,424	116,230
20	10.0	10.00	25,383	128,682
21	10.5			
22	11.0			
23	11.5			
24	12.0			

Prepared by: [signature] Approved by: [signature]

TABLE 2

LOCKHEED PROP SION COMPANY
POTRERO TE T SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

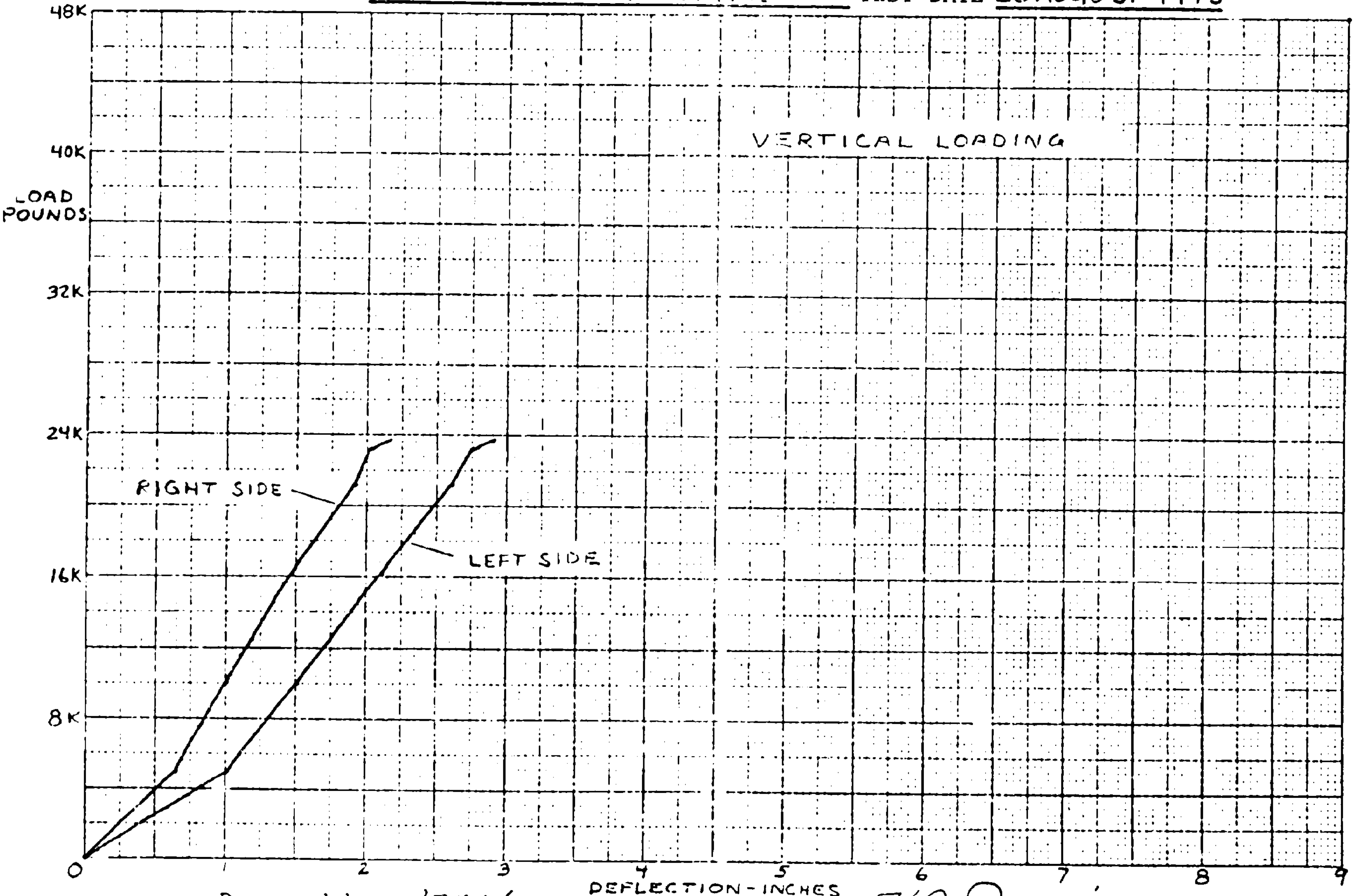
TEST ITEM 6K FORKLIFT PROTOTYPE TEST DATE 28 AUGUST 1973

Prepared by: J M [signature] Approved by: W C Davis

LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K FORKLIFT PROTOTYPE TEST DATE 28 AUGUST 1973



Prepared by: Approved by:

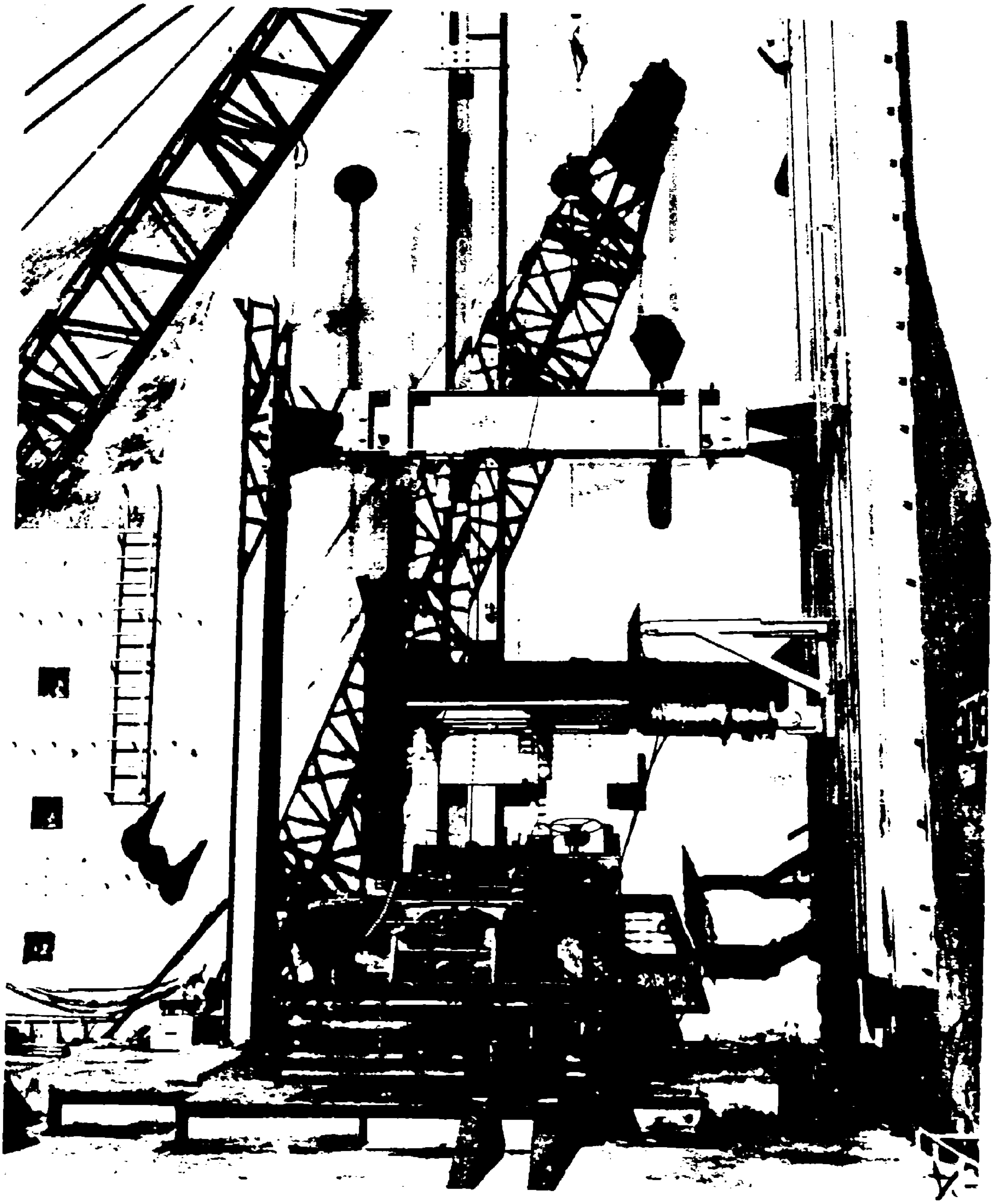


Figure 1 - Test Set Up

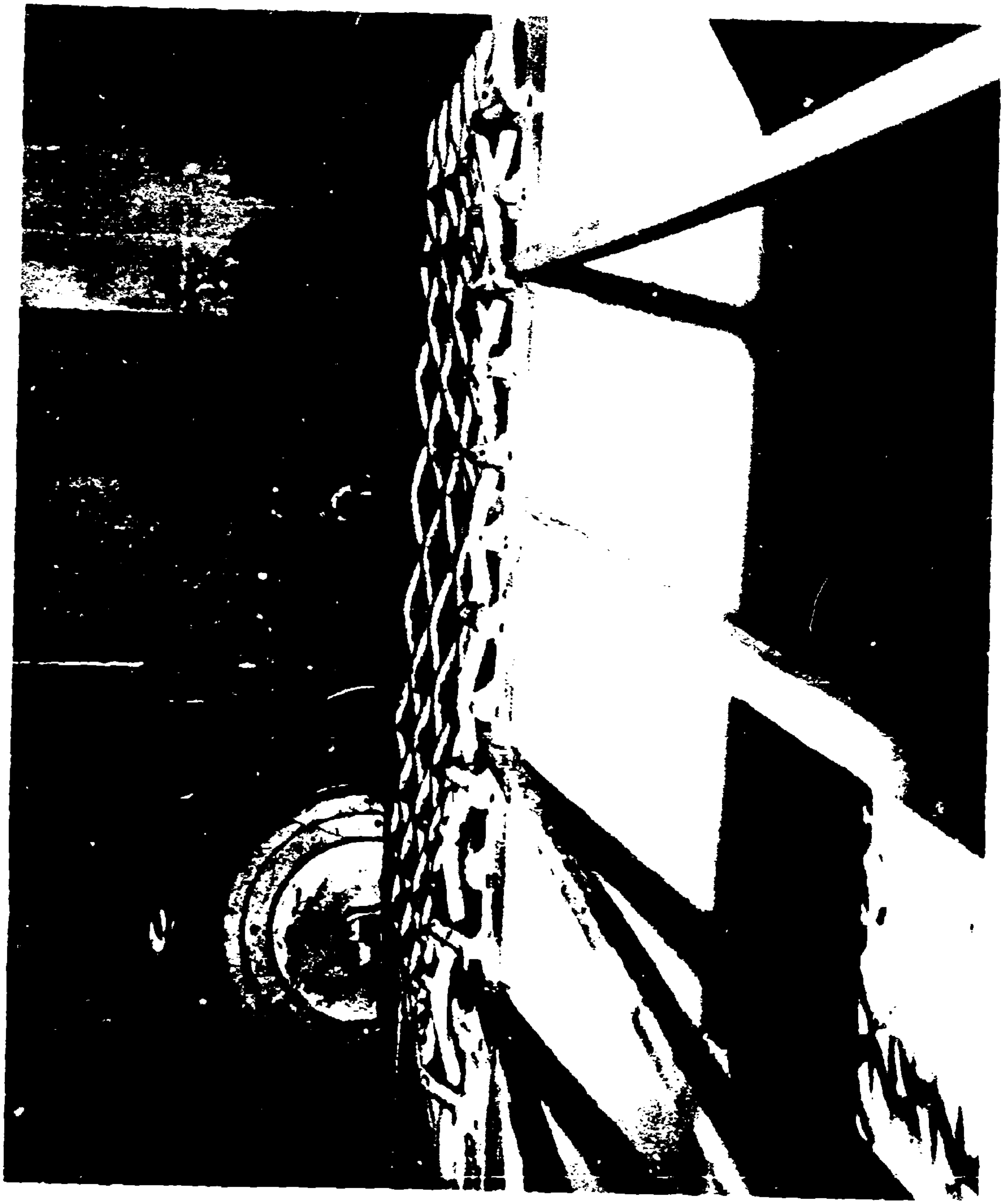


Figure 2 - Top View After FOPS Test

10350

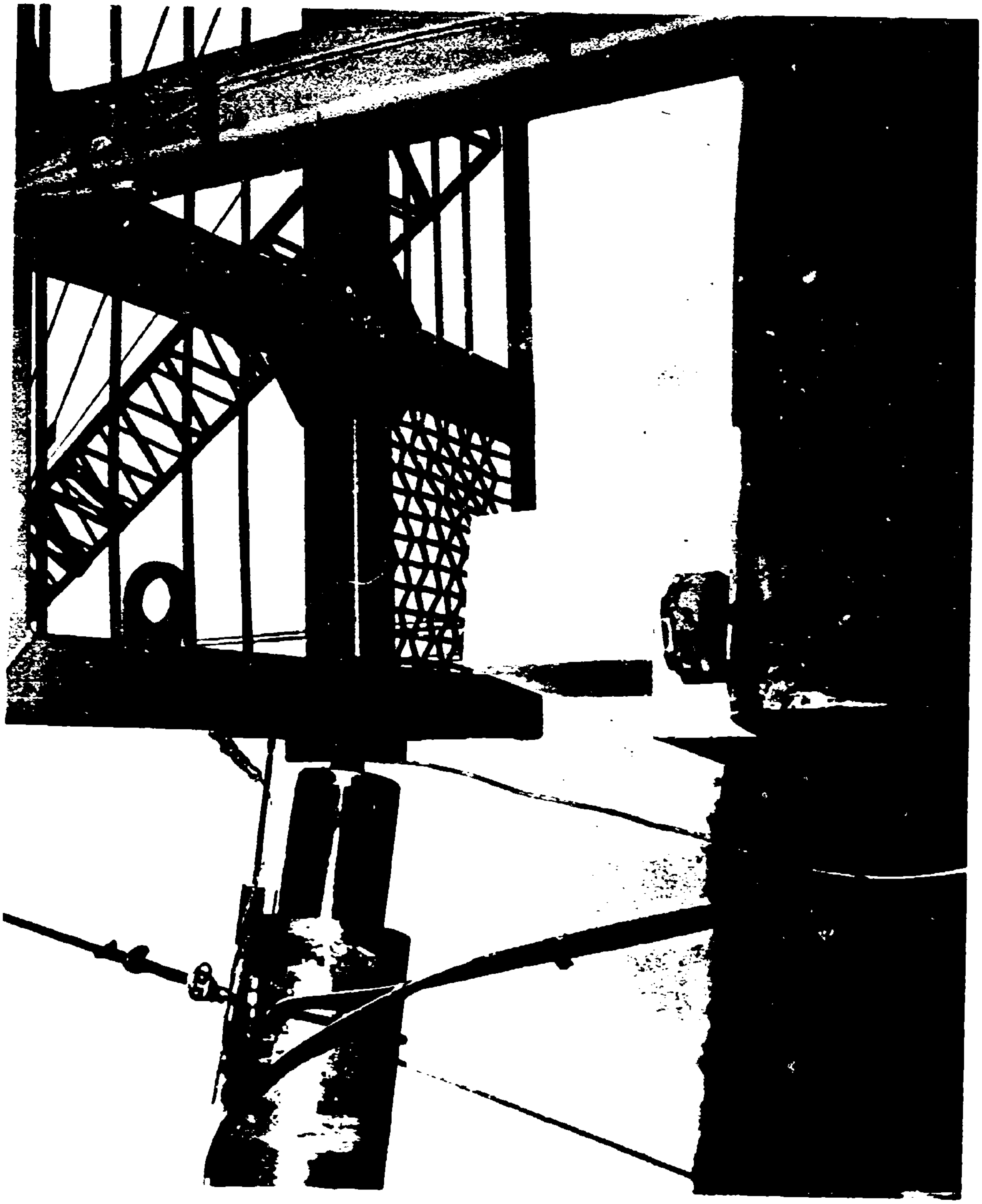


Figure 3 - Maximum Horizontal Deflection

10352

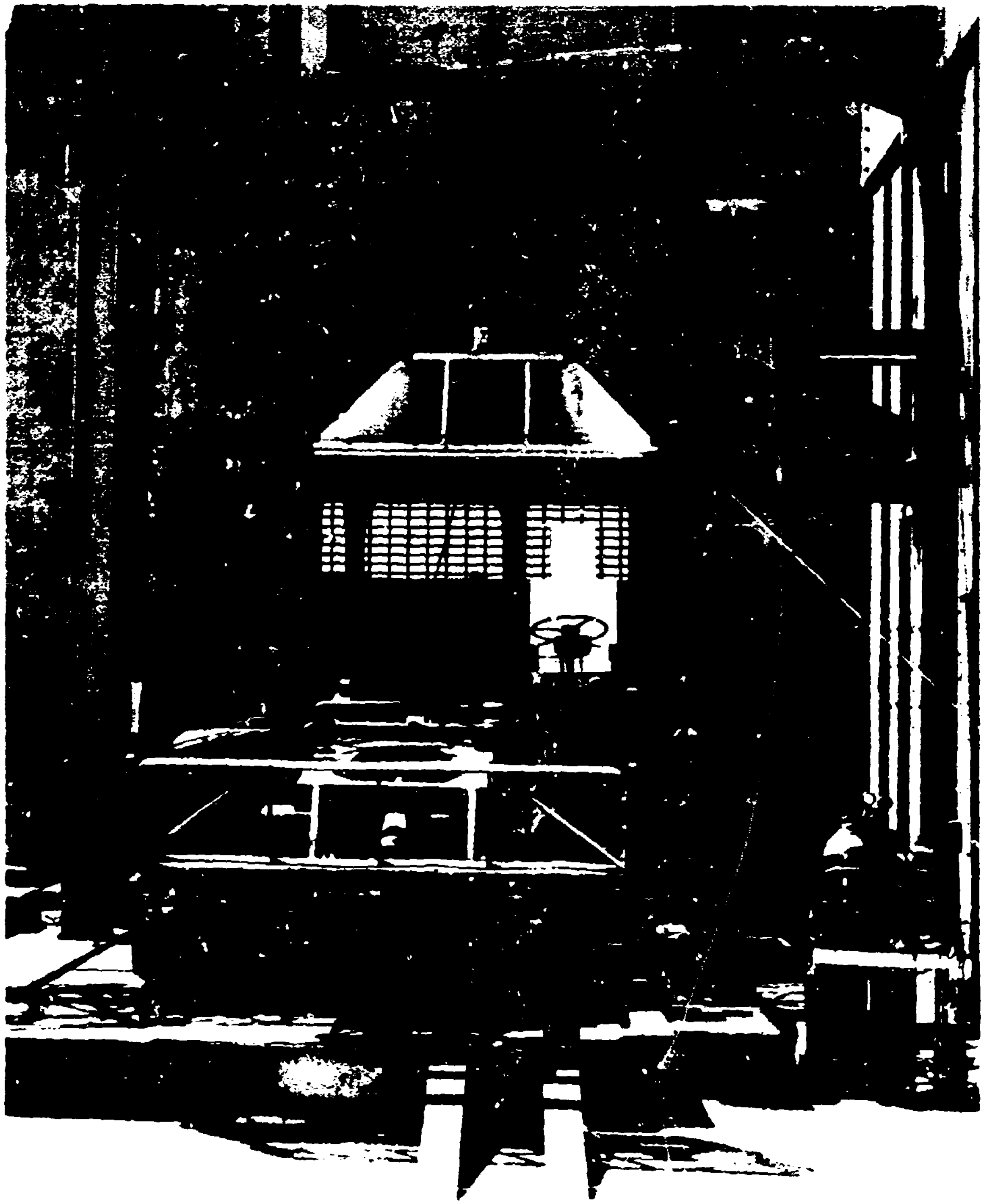
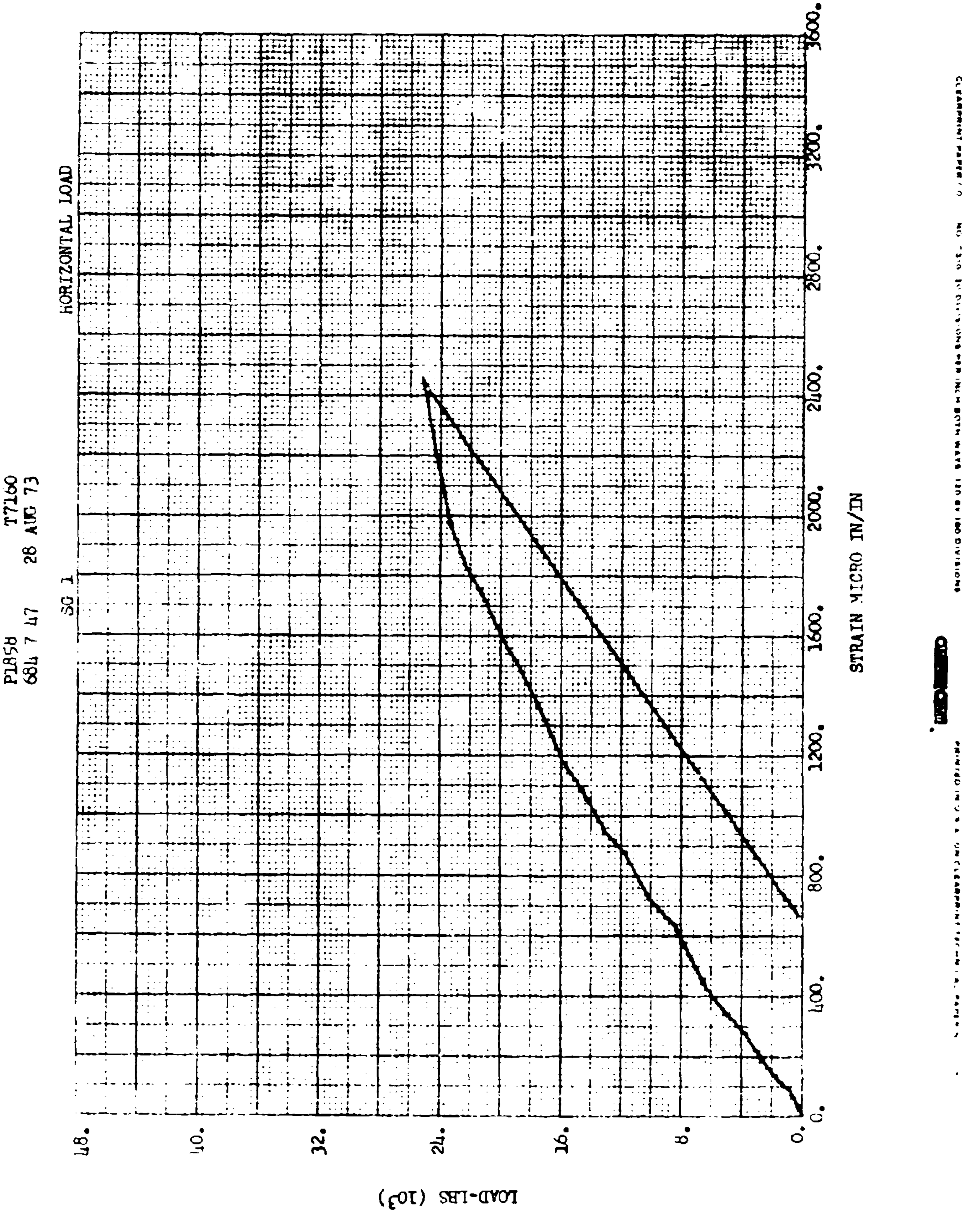


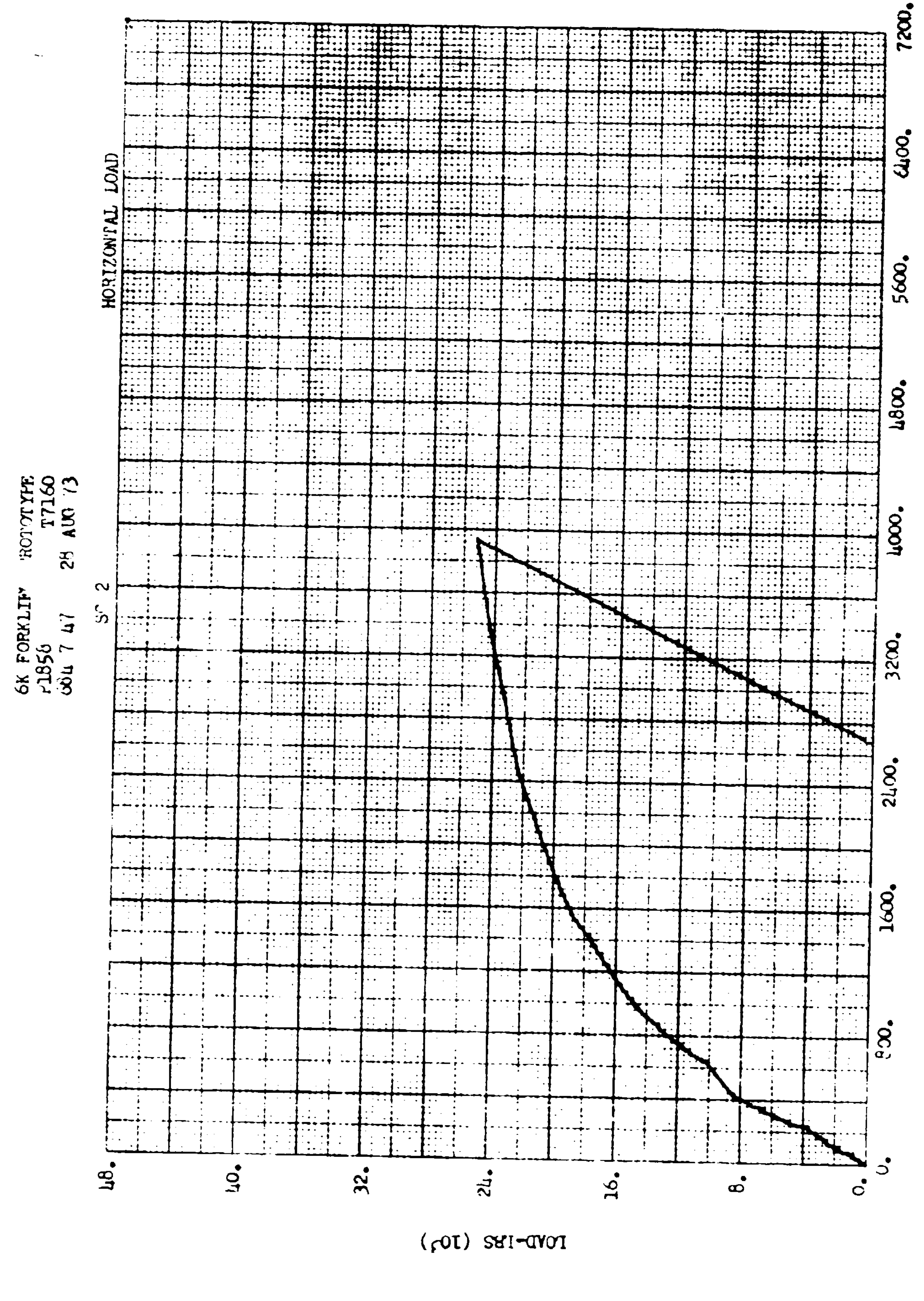
Figure 4 - Vertical Loading Set Up

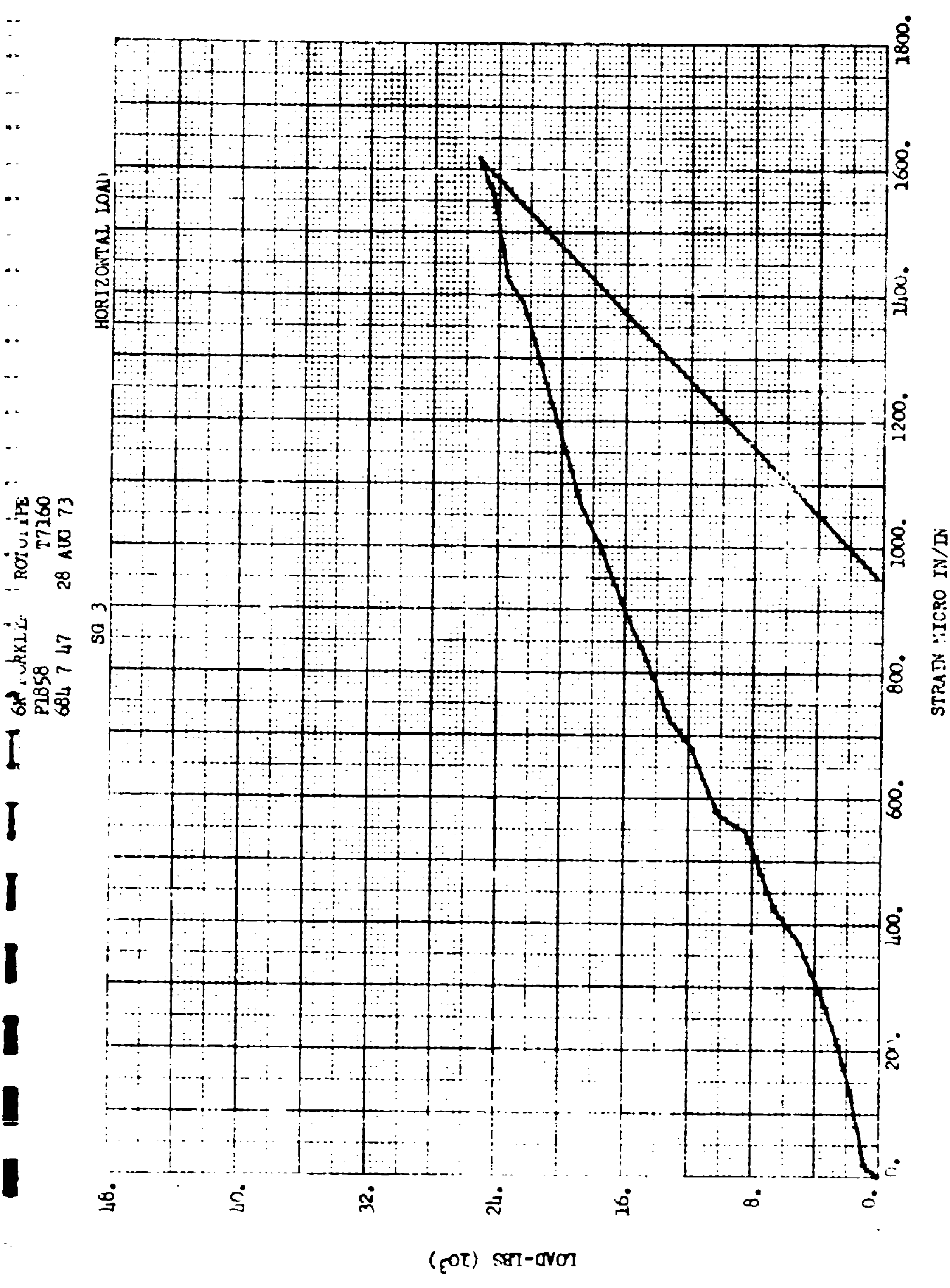
TR-684-065

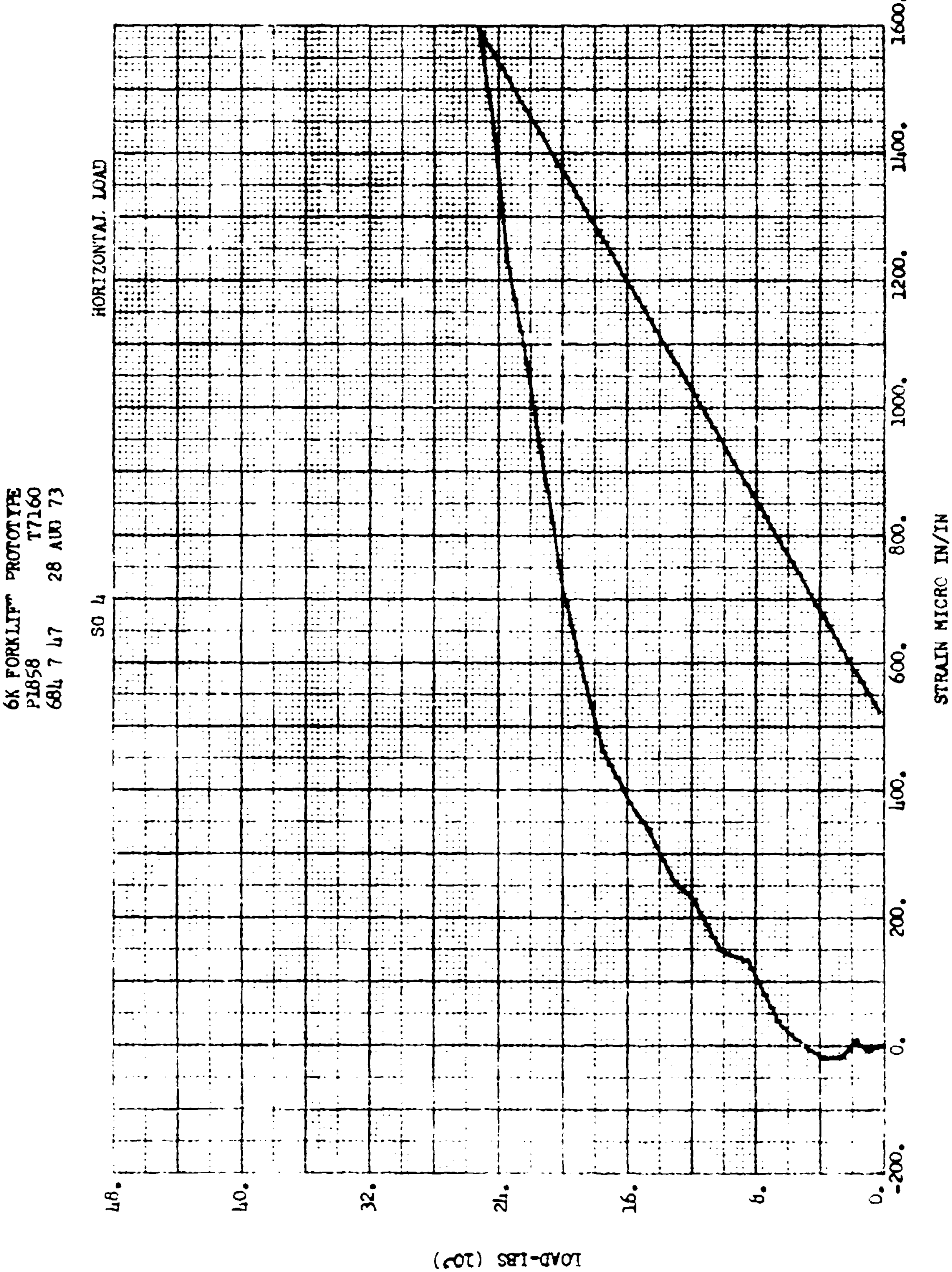
ADDENDUM I

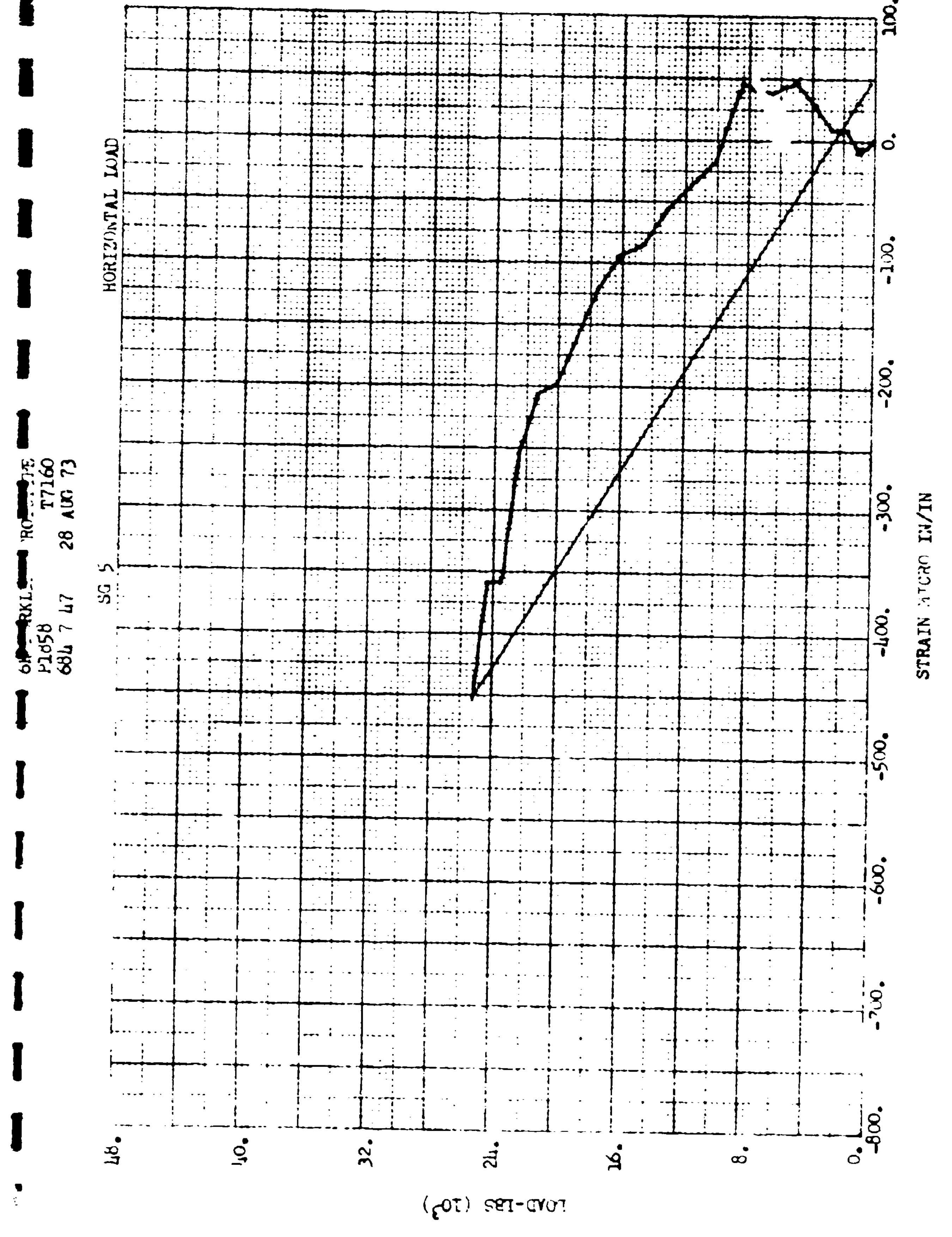
PLOTS OF STRAIN VERSUS LOAD DURING HORIZONTAL LOADING

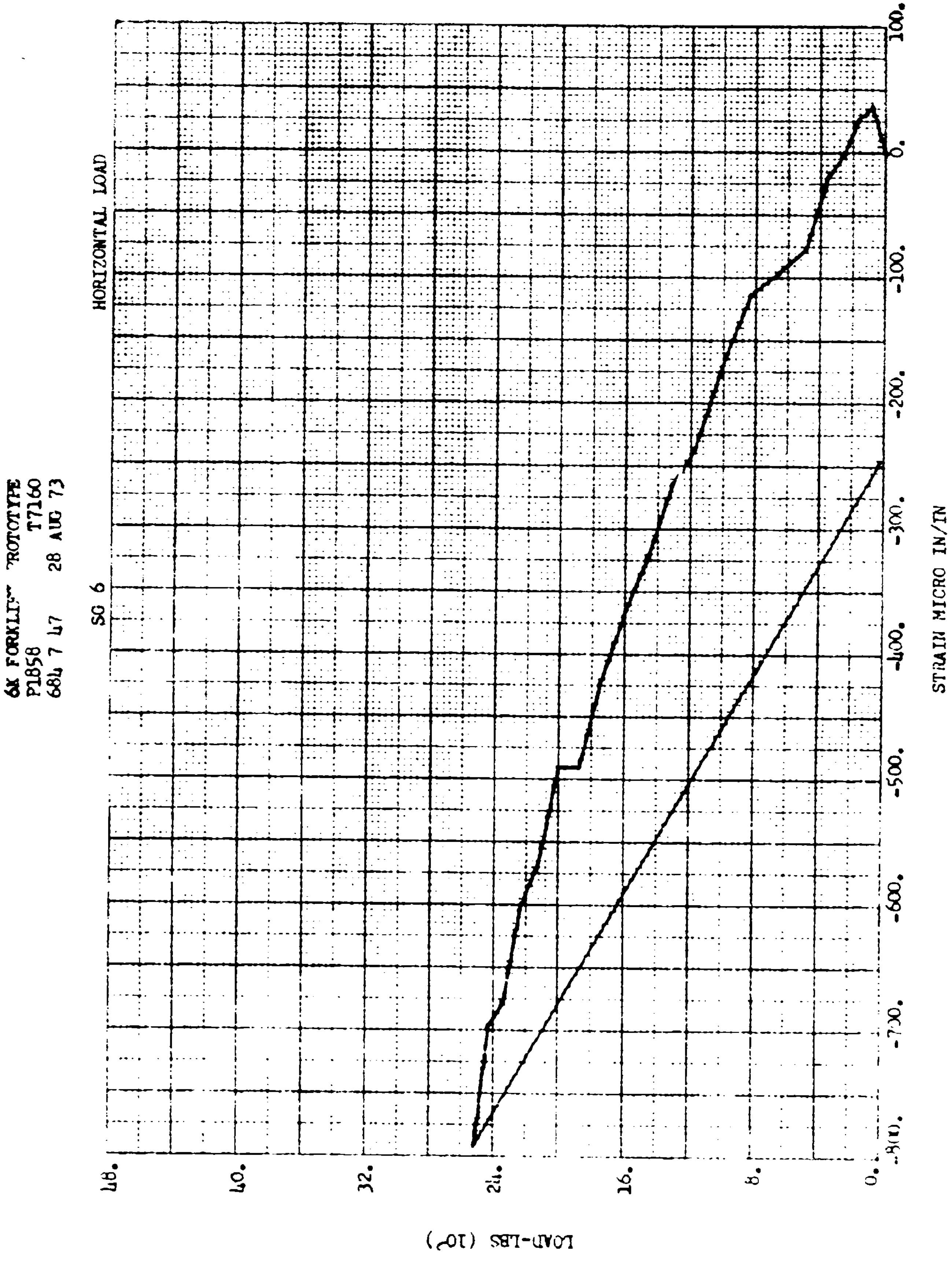

P1858 T7160
684 7 47 28 AUG 73
SG 1
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0. 400. 800. 1200. 1600. 2000. 2400. 2800. 3200. 3600.
0. 8. 16. 24. 32. 40. 48.

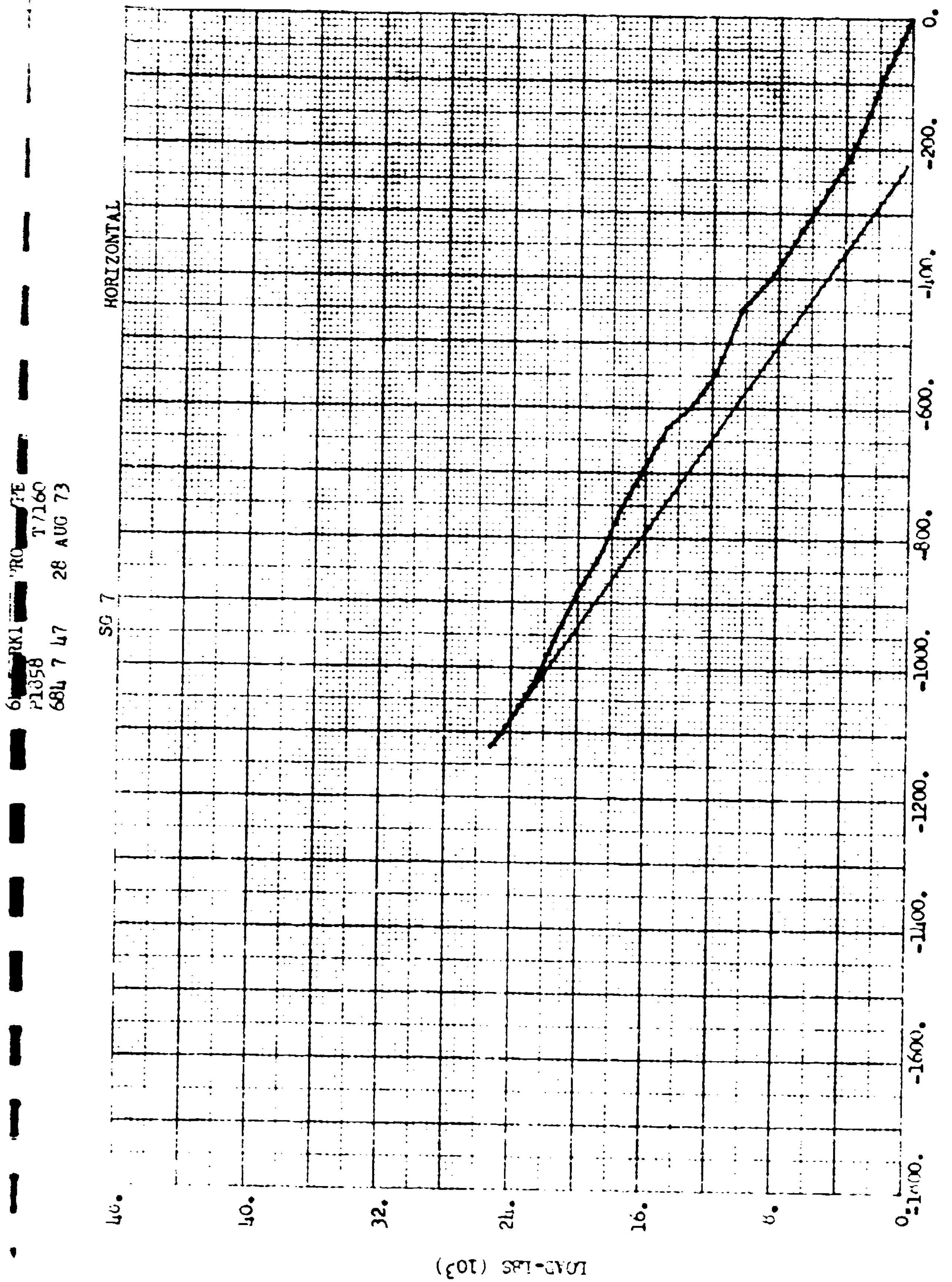

6K FORKLIFT PROTOTYPE
T7160
604 7 47
28 AUG 73
SG 2
HORIZONTAL LOAD
STRAIN MICRO IN/IN
0.
800.
1600.
2400.
3200.
4000.
4800.
5600.
6400.
7200.
LOAD-LBS (10^3)
0.
8.
16.
24.
32.
40.
48.

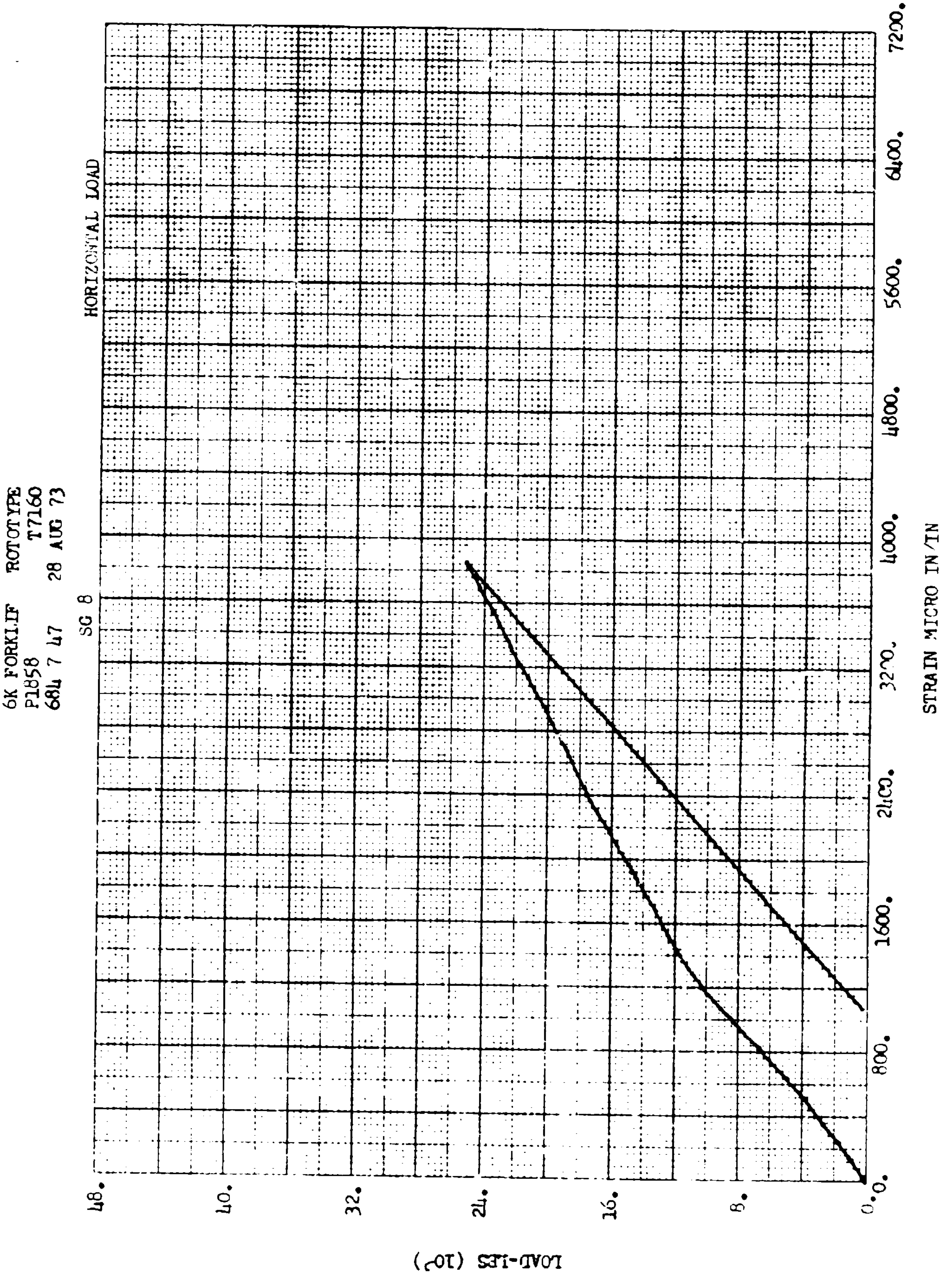

P1B58 T7160
684 7 47 28 AUG 73
SG 3
HORIZONTAL LOAD
STRAIN MICRO IN/IN
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.
LOAD-LBS (10^3)
0.
8.
16.
24.
32.
40.
48.

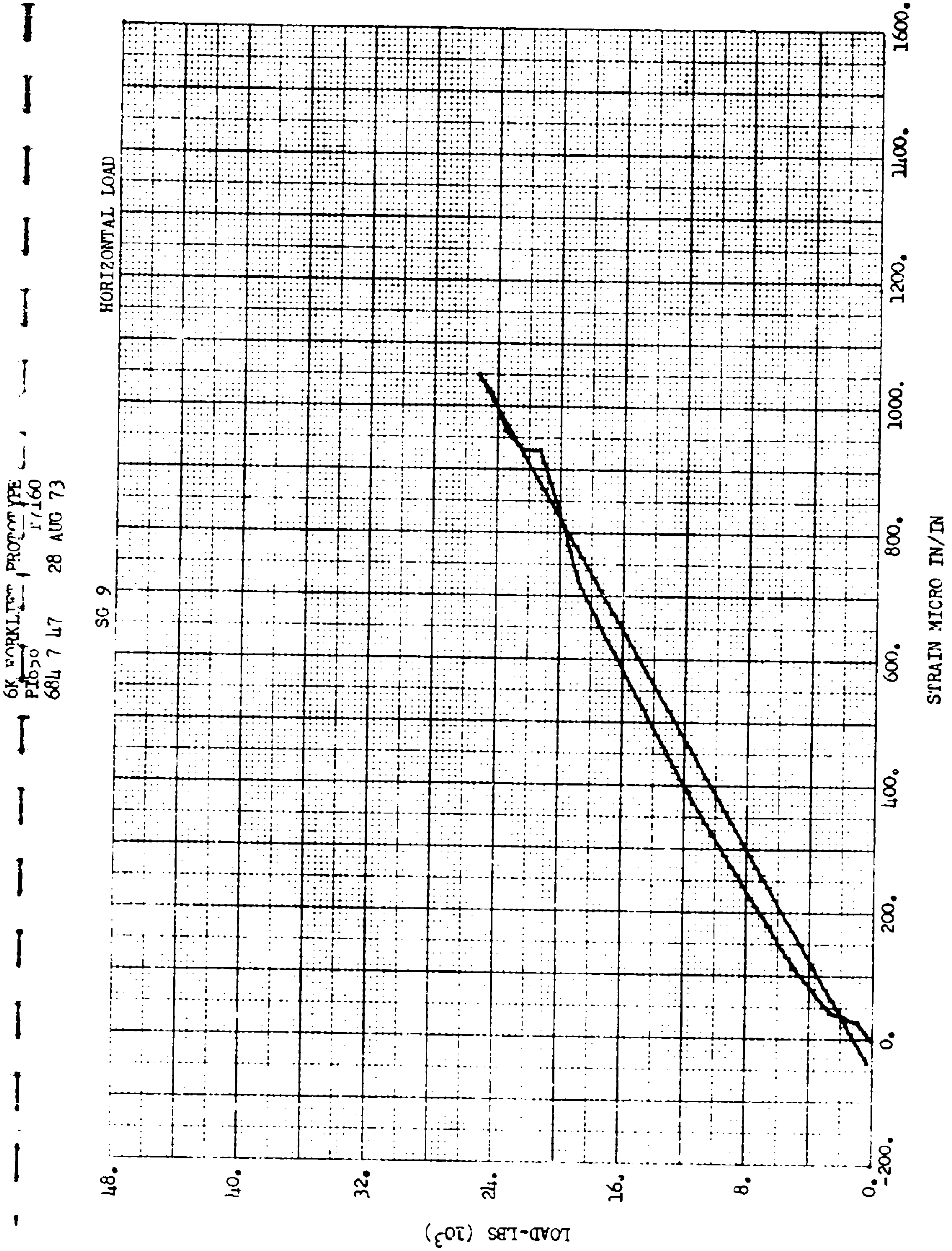

6K FORKLIFT PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 4
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
-200.
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
0.
8.
16.
24.
32.
40.
48.


6[redacted]RKL[redacted] RO[redacted]E
P1058 T7160
684 7 47 28 AUG 73
SG 5
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
48.
40.
32.
24.
16.
8.
0.
100.
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.


6K FORKLIFT PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 6
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
100.
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
48.
40.
32.
24.
16.
8.
0.


6[redacted]RKI[redacted]RO[redacted]TE
P1358 T7160
684 7 47 28 AUG 73
SG 7
HORIZONTAL
STRAIN MICRO IN/IN
0.
-200.
-400.
-600.
-800.
-1000.
-1200.
-1400.
-1600.
-1800.
LOAD-LBS (10^3)
0.
8.
16.
24.
32.
40.
48.


6K FORKLIF ROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 8
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
800.
1600.
2400.
3200.
4000.
4800.
5600.
6400.
7200.
0.0
8.
16.
24.
32.
40.
48.


684 7 47
28 AUG 73
SG 9
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
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0.
200.
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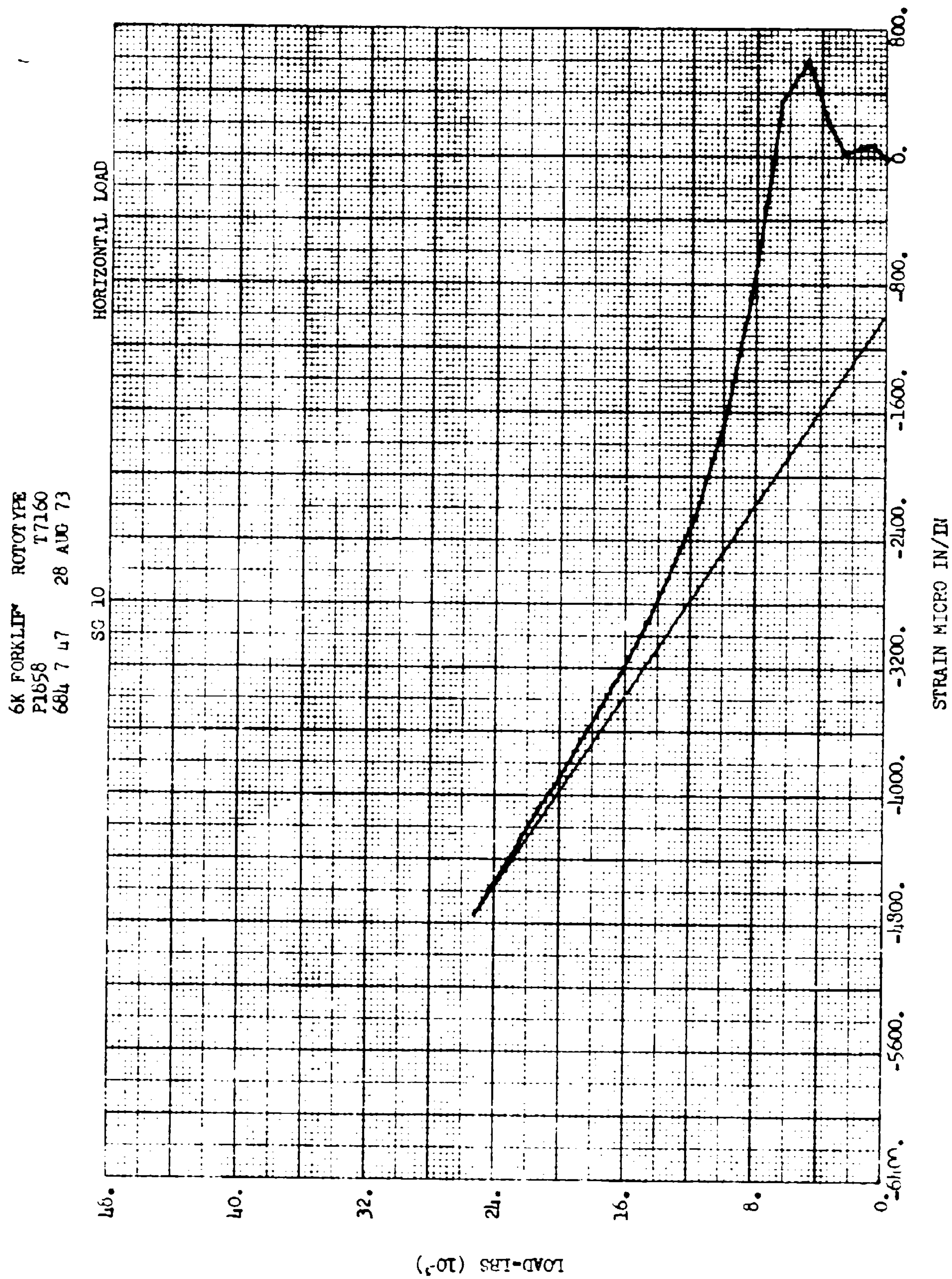
600.
800.
1000.
1200.
1400.
1600.
0.
8.
16.
24.
32.
40.
48.


6K FORKLIFT ROTOTYPE
P1658 T7160
684 7 47 28 AUG 73
SG 10
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
48.
40.
32.
24.
16.
8.
0.
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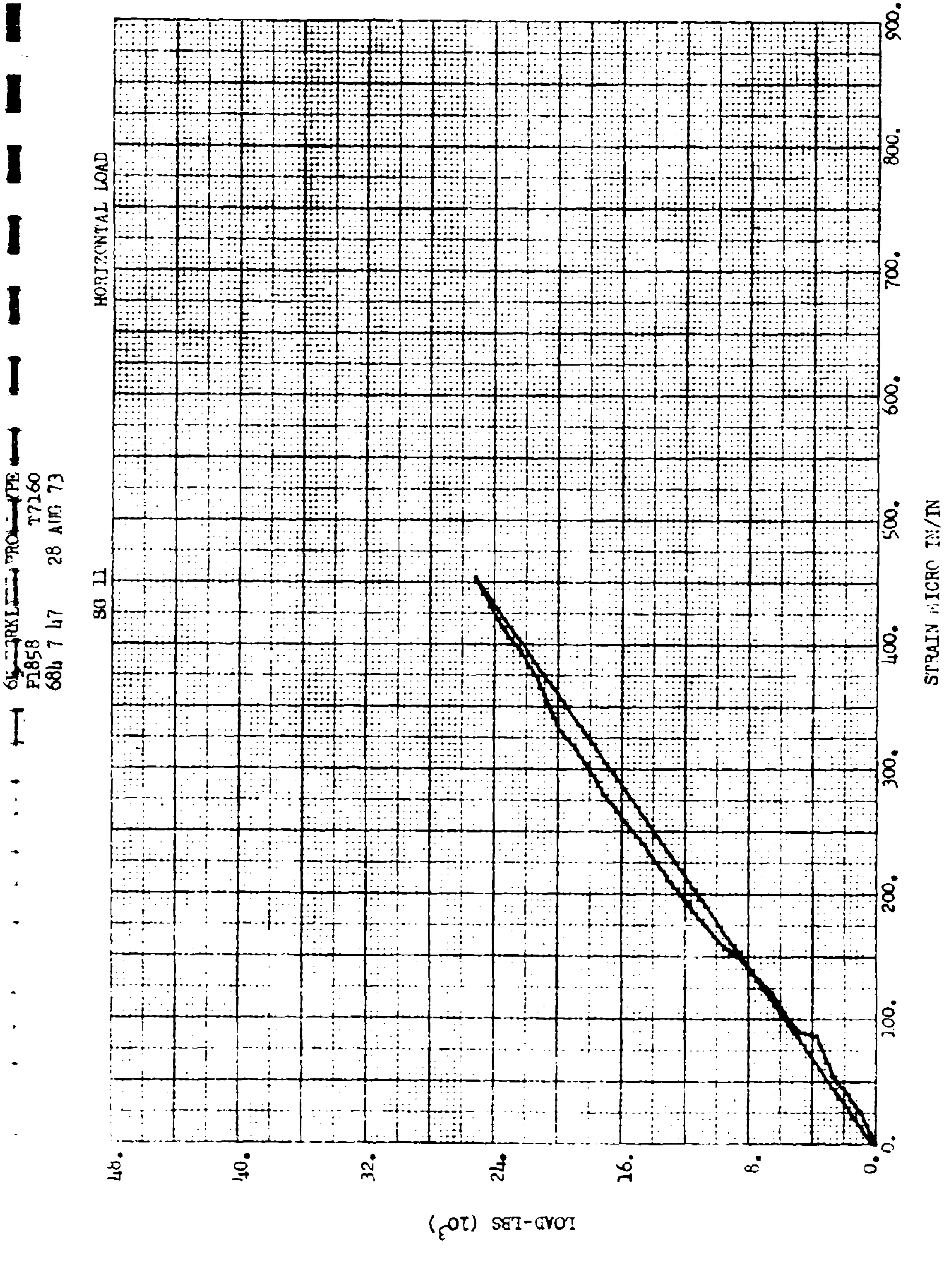
0.
-800.
-1600.
-2400.
-3200.
-4000.
-4800.
-5600.
-6400.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SG 11
P1858
684 7 47
T7160
28 AUG 73
STRAIN MICRO IN/IN
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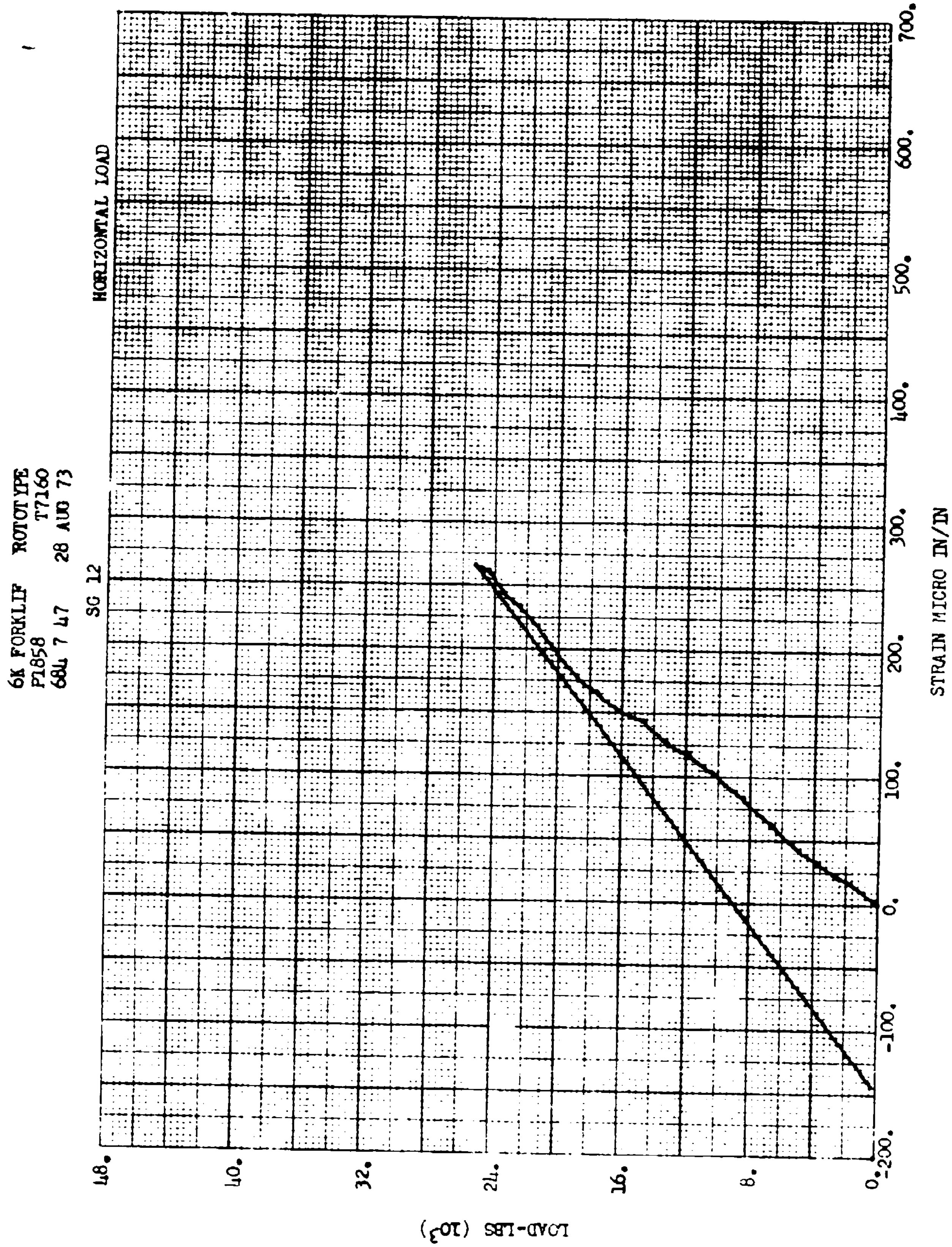
200.
300.
400.
500.
600.
700.
800.
900.
LOAD-LBS (10^3)
0.
8.
16.
24.
32.
40.
48.


6K FORKLIF ROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 12
HORIZONTAL LOAD
STRAIN MICRO IN/IN
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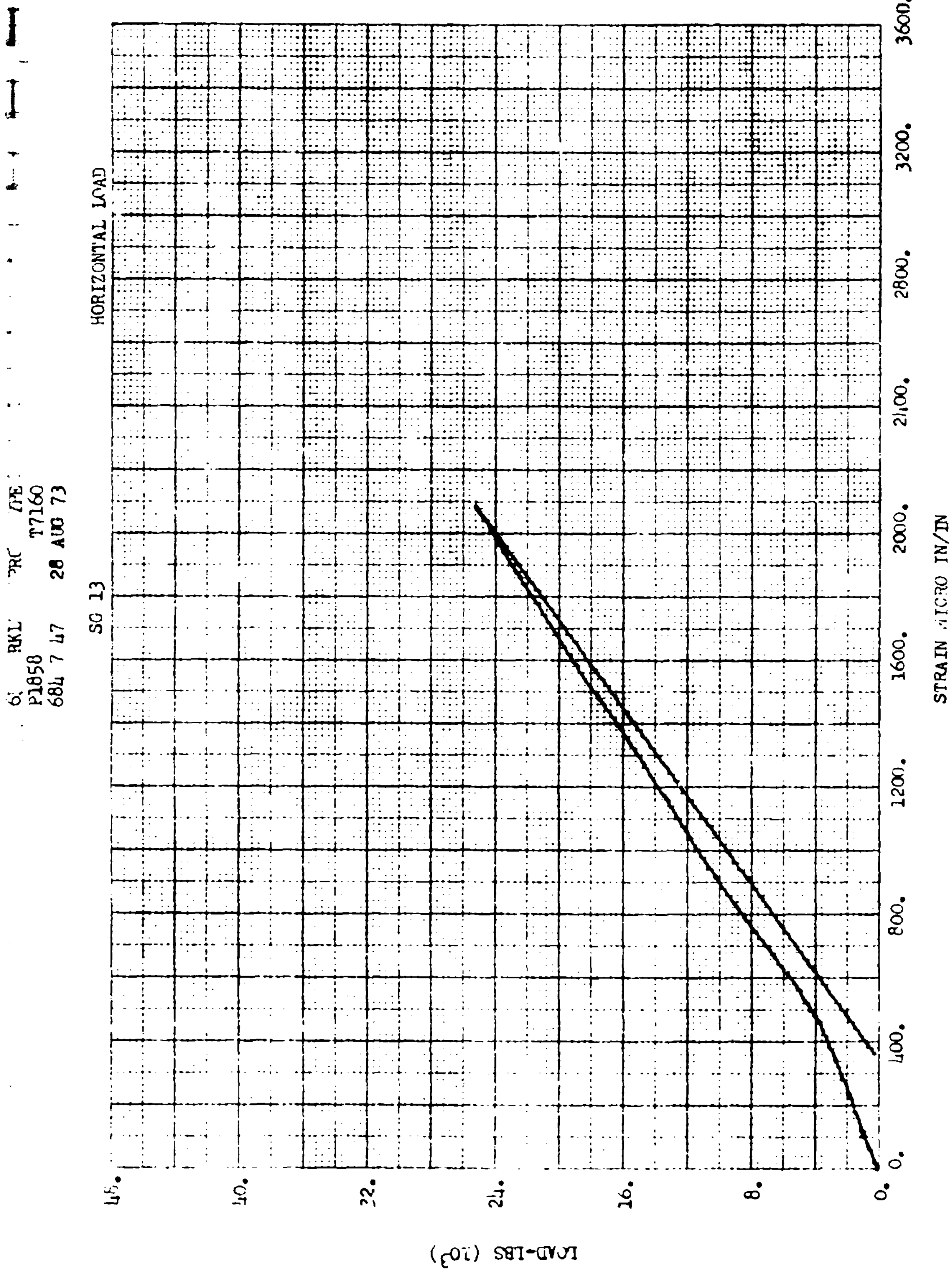
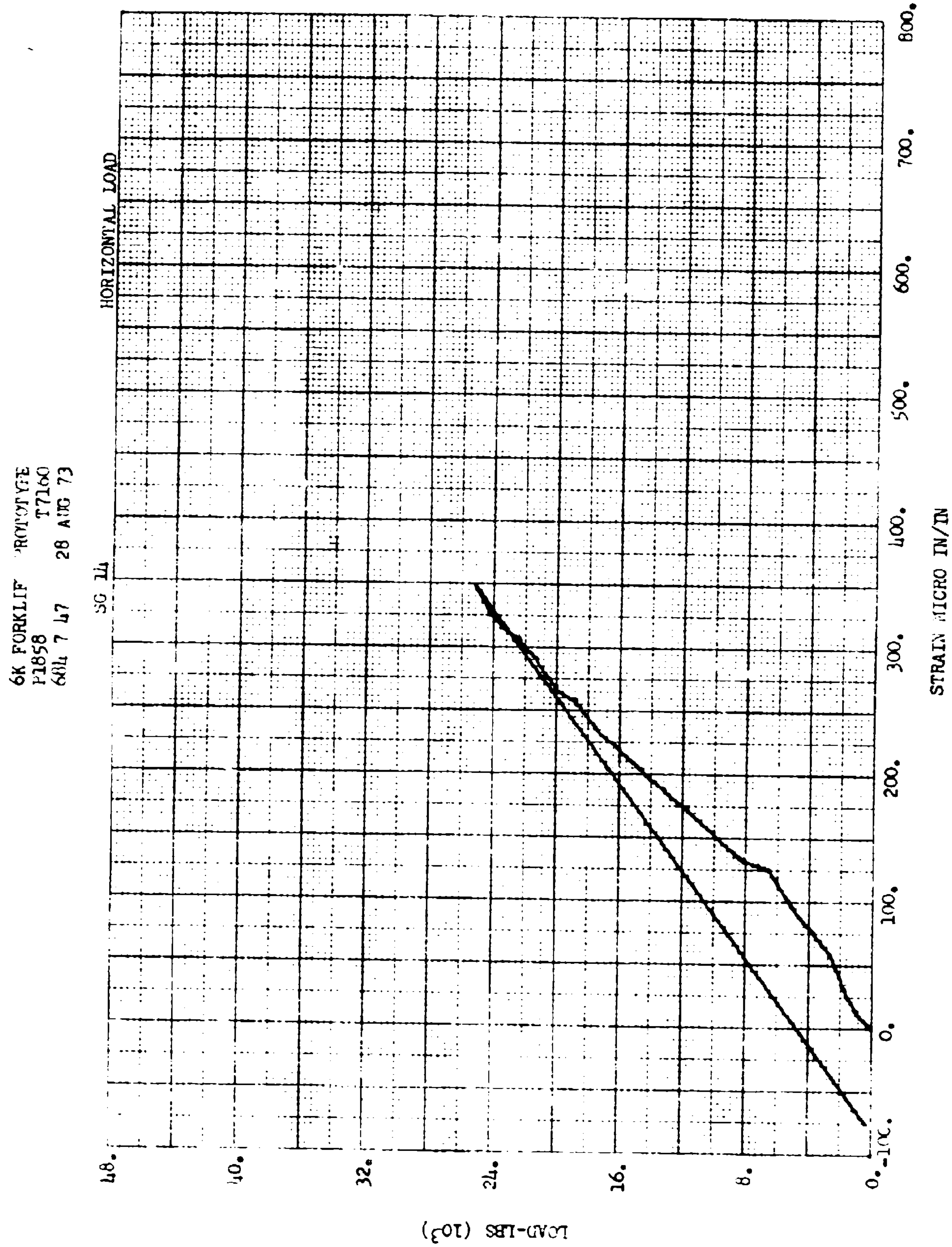
-100.
0.
100.
200.
300.
400.
500.
600.
700.
LOAD-LBS (10³)
0.
8.
16.
24.
32.
40.
48.


P1858
684 7 47
T7160
28 AUG 73
SG 13
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.
3600.
8.
16.
24.
32.
40.
48.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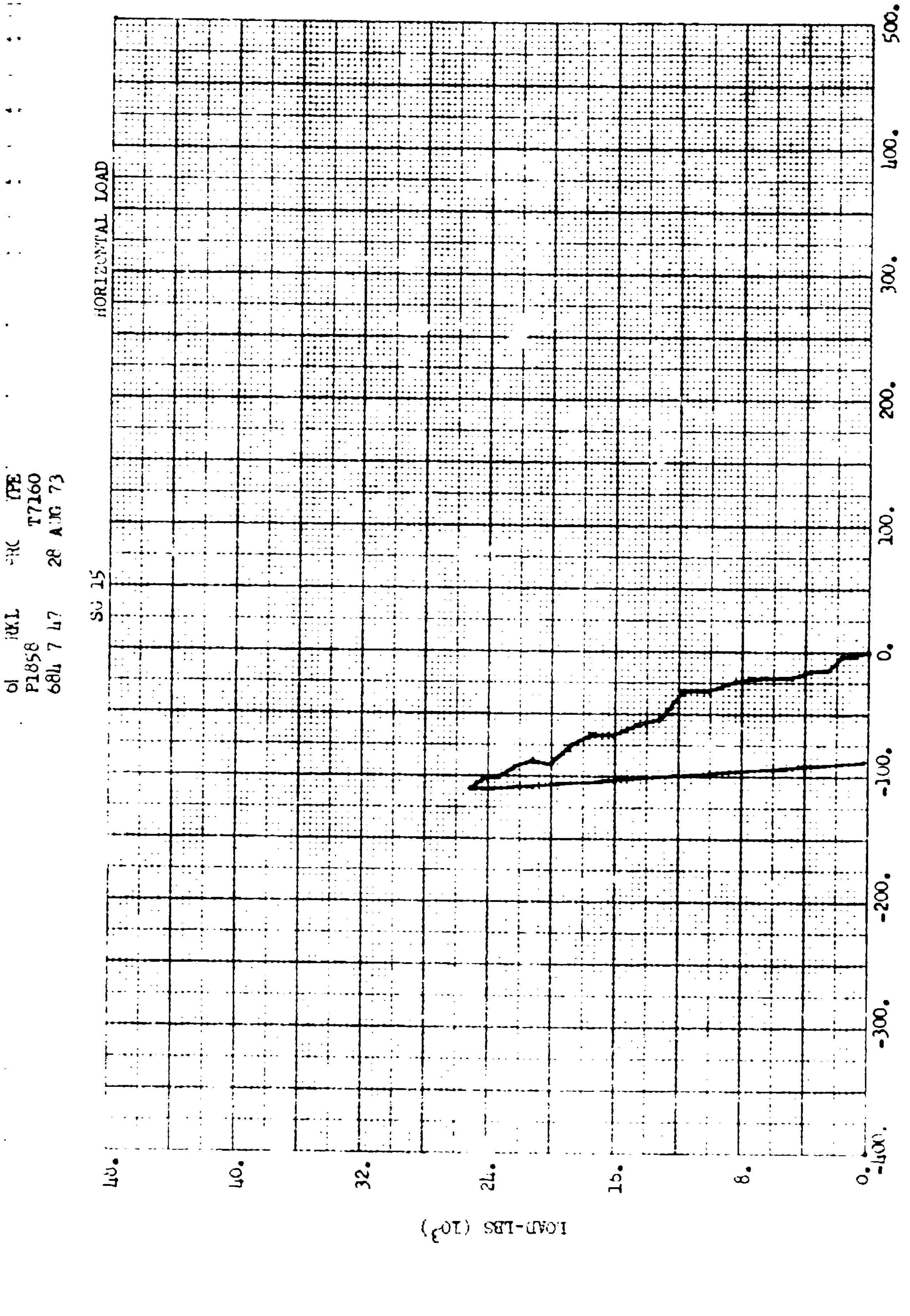
P1858 T7160
684 7 47 28 AUG 73
SG 14
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
8.
16.
24.
32.
40.
48.
-100.
0.
100.
200.
300.
400.
500.
600.
700.
800.


01 RKL
P1858 T7160
684 7 47 28 AUG 73
SG 15
HORIZONTAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
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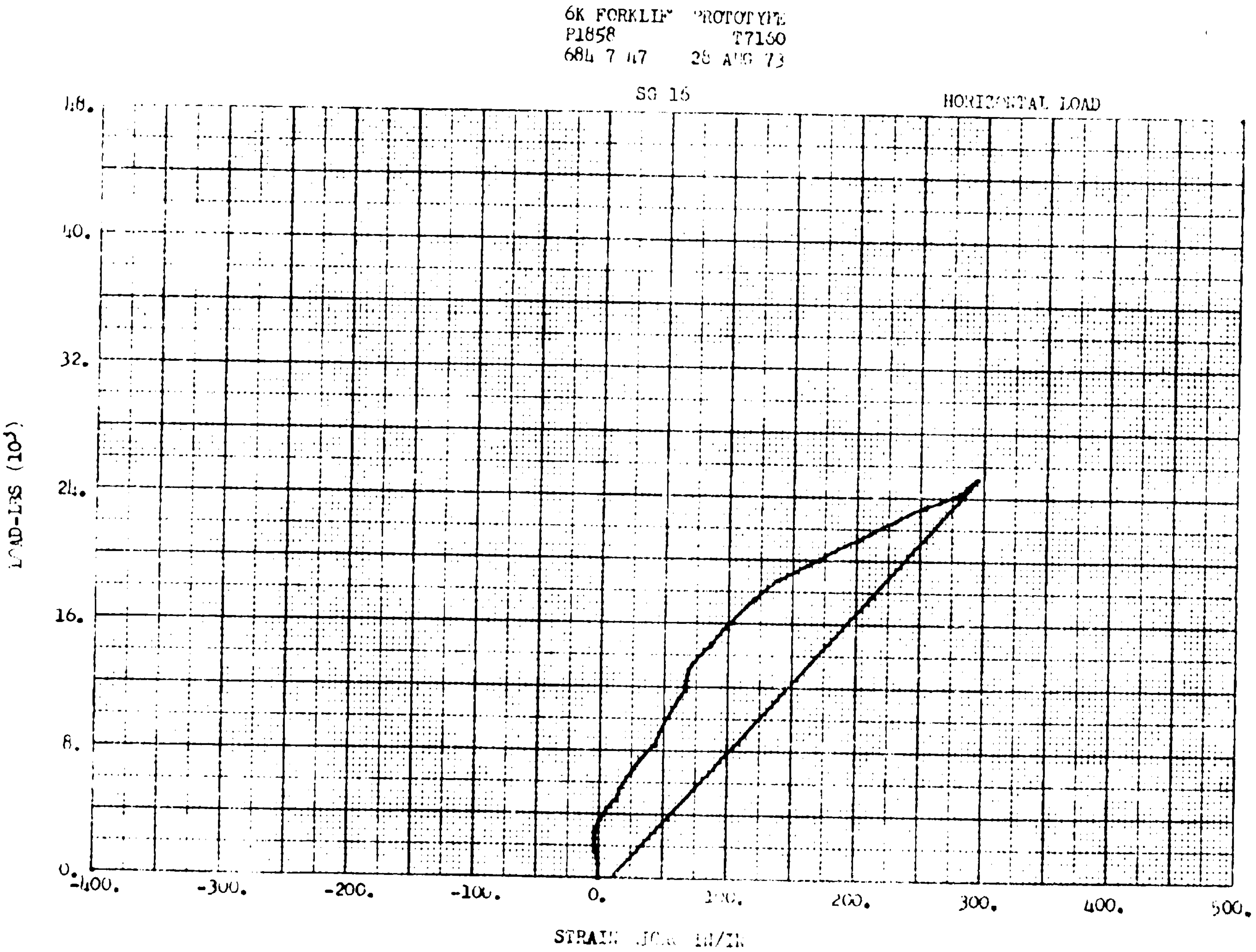
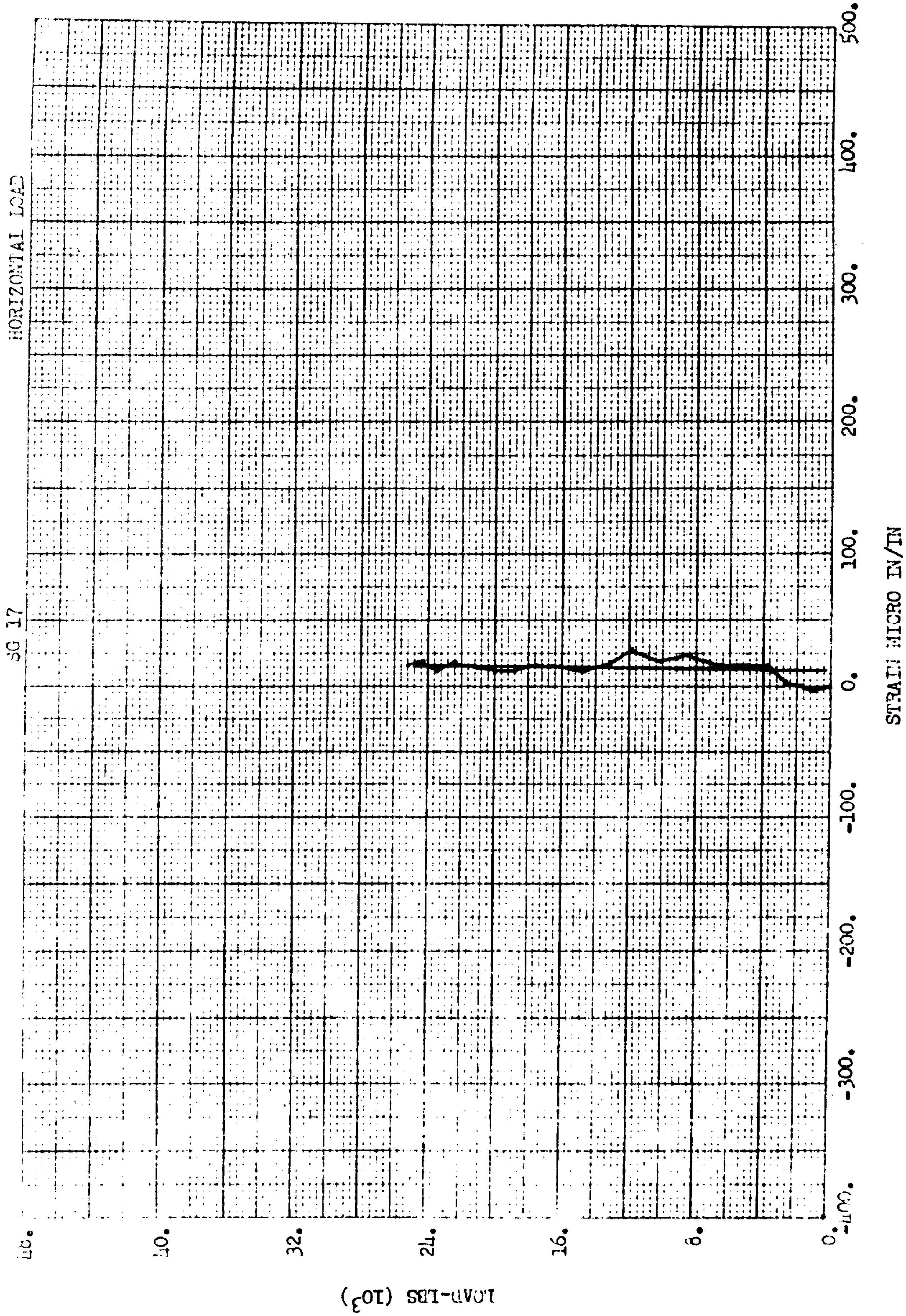
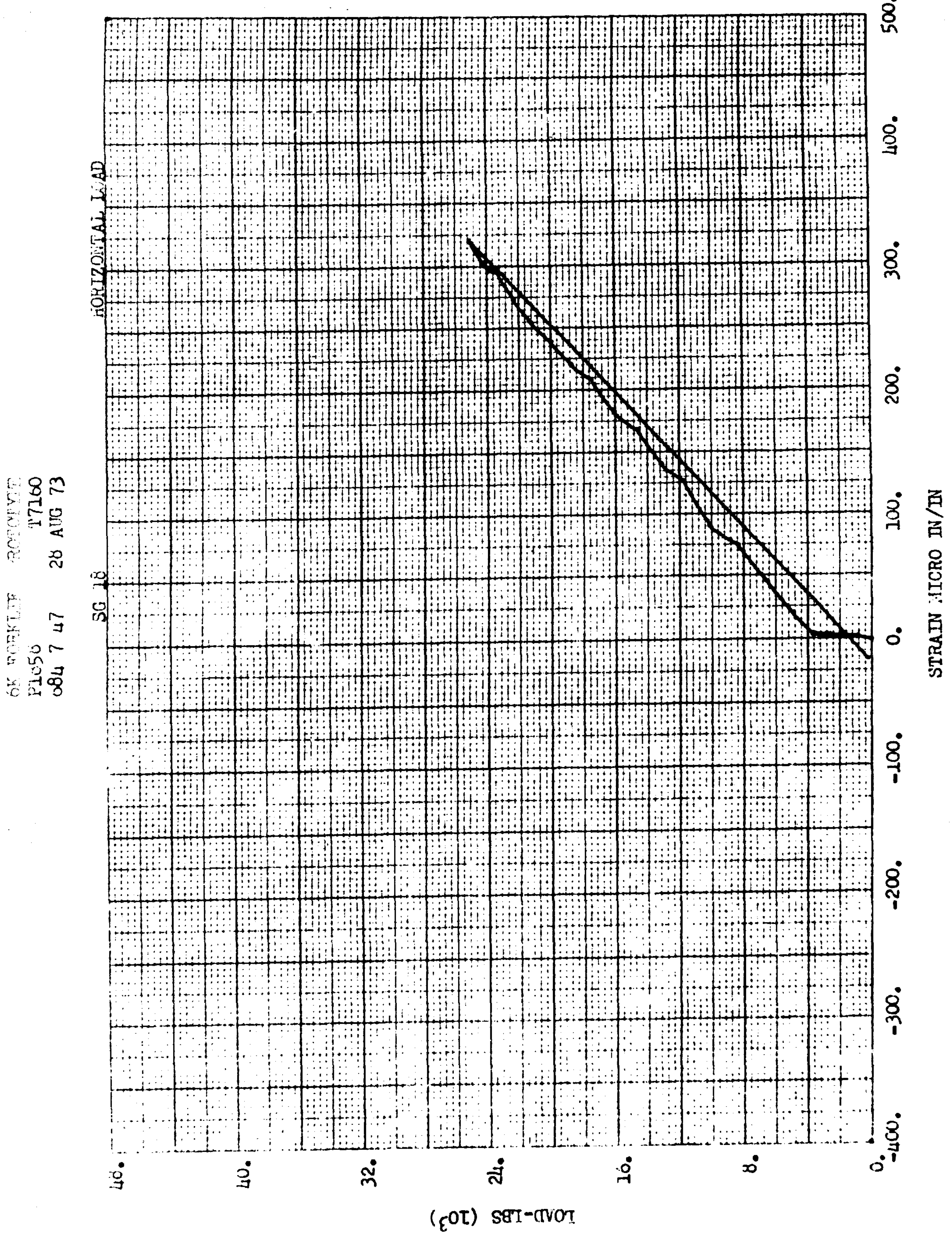
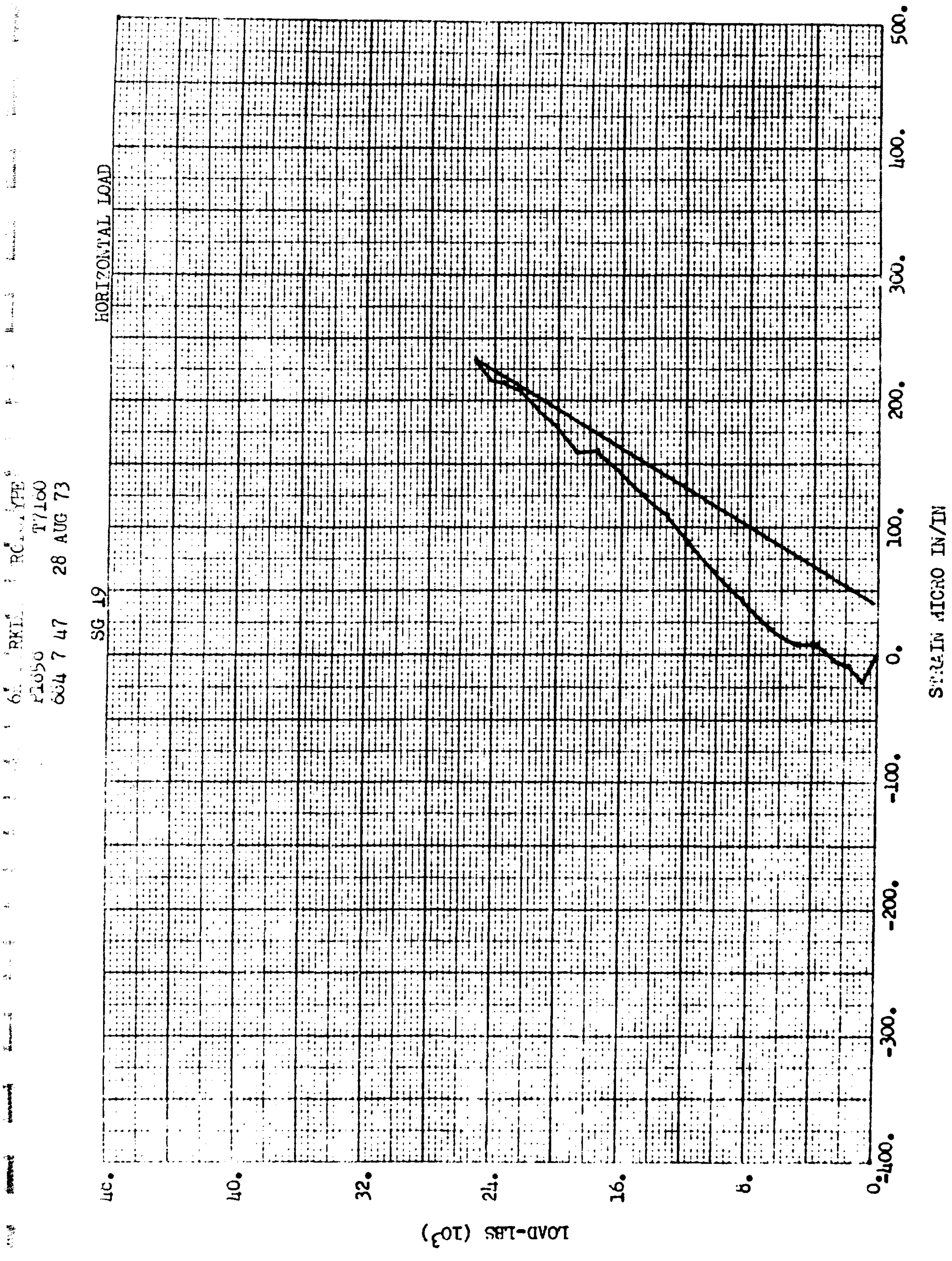
400.
300.
200.
100.
0.
-100.
-200.
-300.
-400.
48.
40.
32.
24.
16.
8.
0.

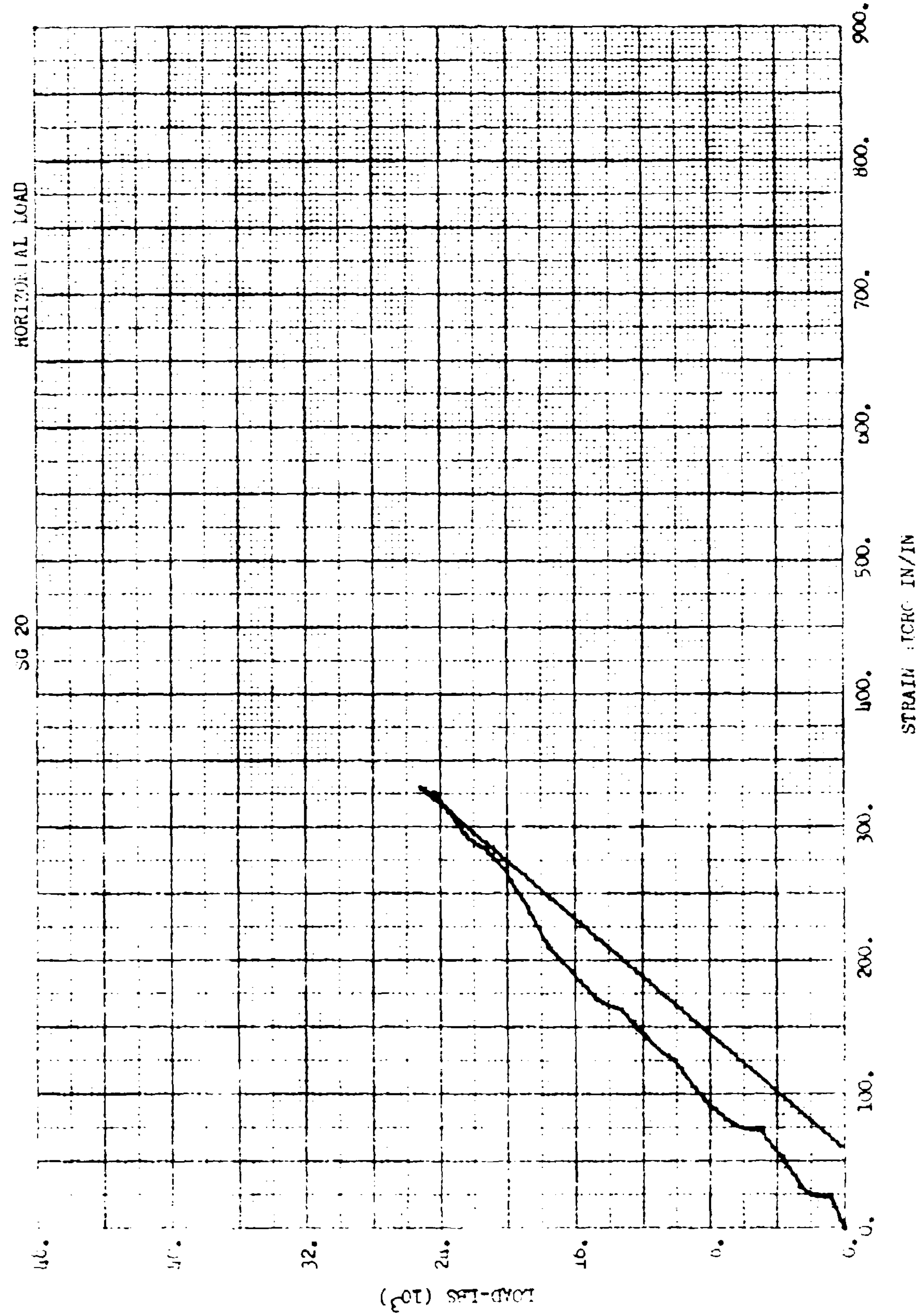

6K FORKLIFT PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 16
HORIZONTAL LOAD
48.
40.
32.
24.
16.
8.
0.
-400.
-300.
-200.
-100.
0.
100.
200.
300.
400.
500.
LOAD-LBS (10^3)
STRAIN MICRO IN/IN


HORIZONTAL LOAD
SG 17
P1856
T7160
20 AUG 75
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
500.
400.
300.
200.
100.
0.
-100.
-200.
-300.
-400.
48.
40.
32.
24.
16.
8.
0.


P1656 T7160
684 7 47 28 AUG 73
SG 18
HORIZONTAL LOAD
STRAIN MICRO IN/IN
500.
400.
300.
200.
100.
0.
-100.
-200.
-300.
-400.
LOAD-LBS (10³)
48.
40.
32.
24.
16.
8.
0.


HORIZONTAL LOAD
T7160
28 AUG 73
SG 19
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
500.
400.
300.
200.
100.
0.
-100.
-200.
-300.
-400.
48.
40.
32.
24.
16.
8.
0.

6K FORKLIFT PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73

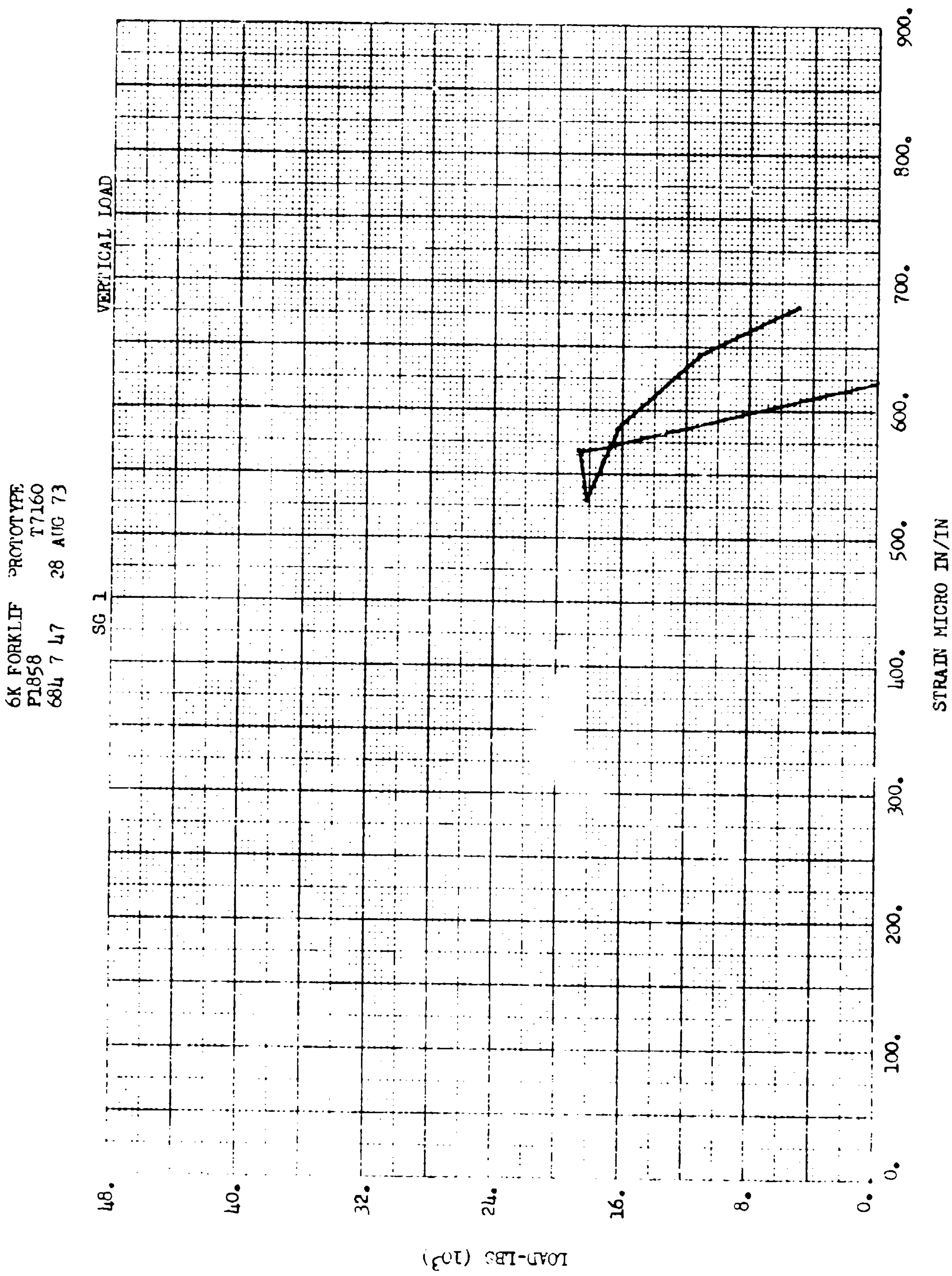


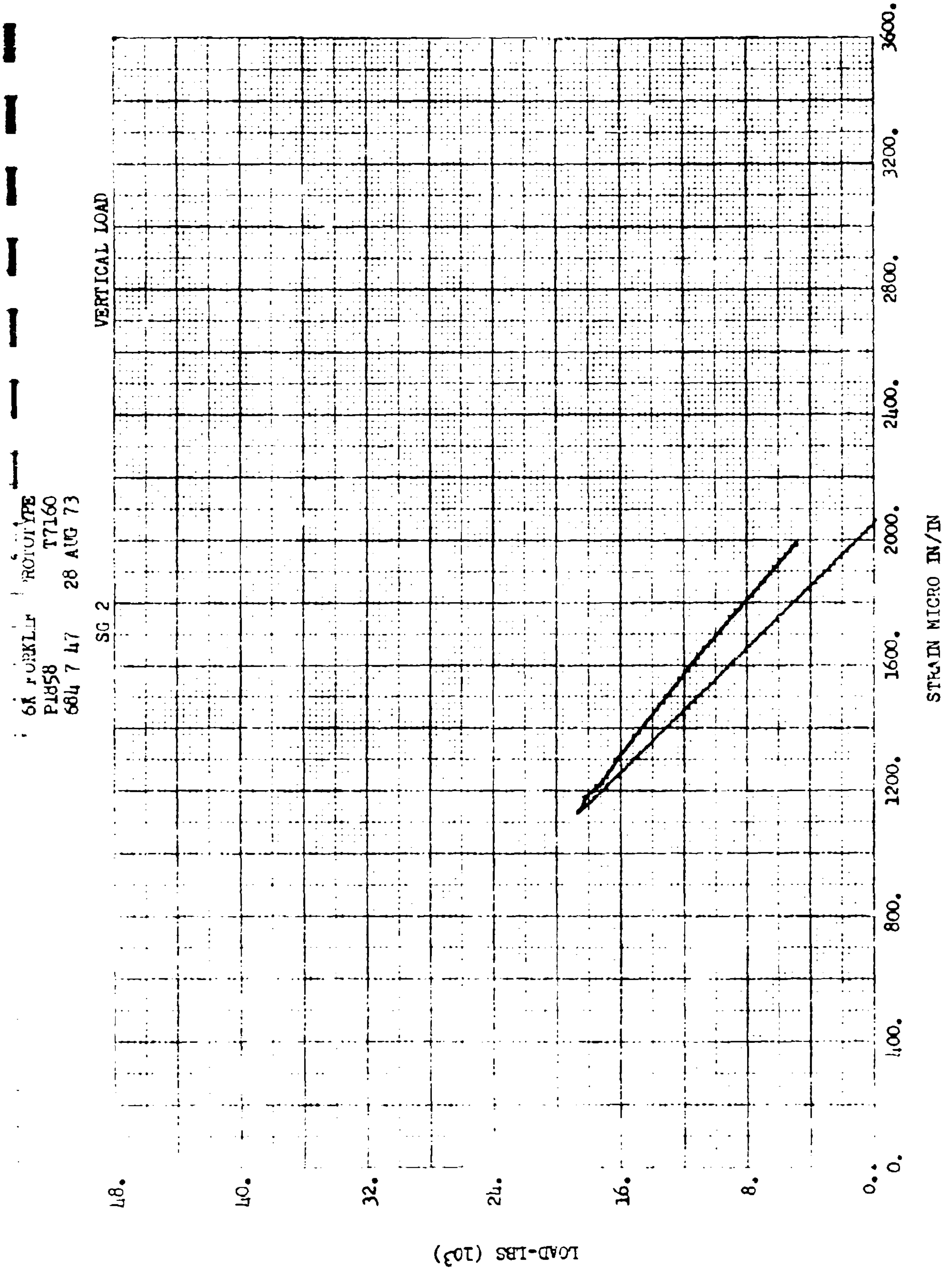
TR-684-065

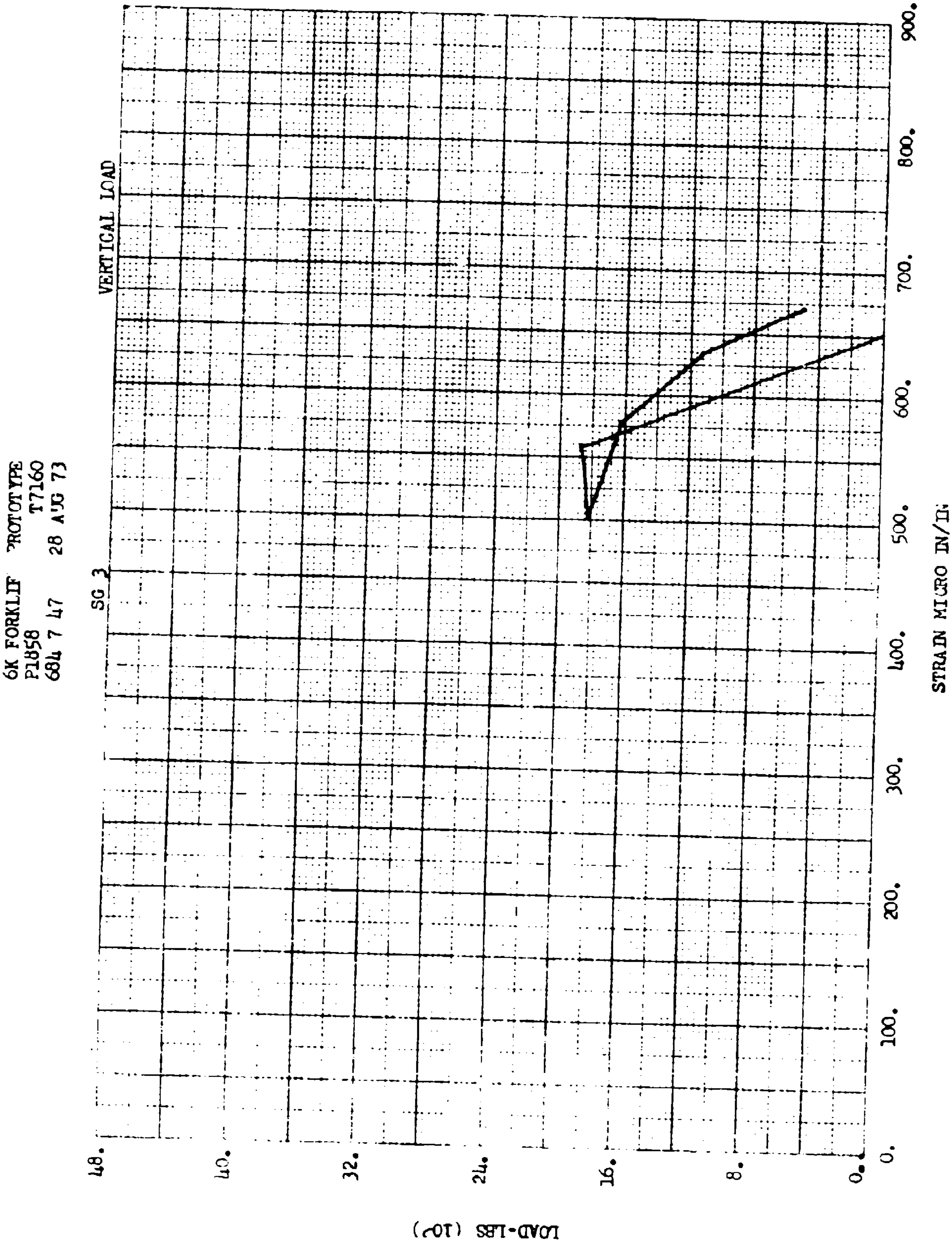
ADDENDUM II

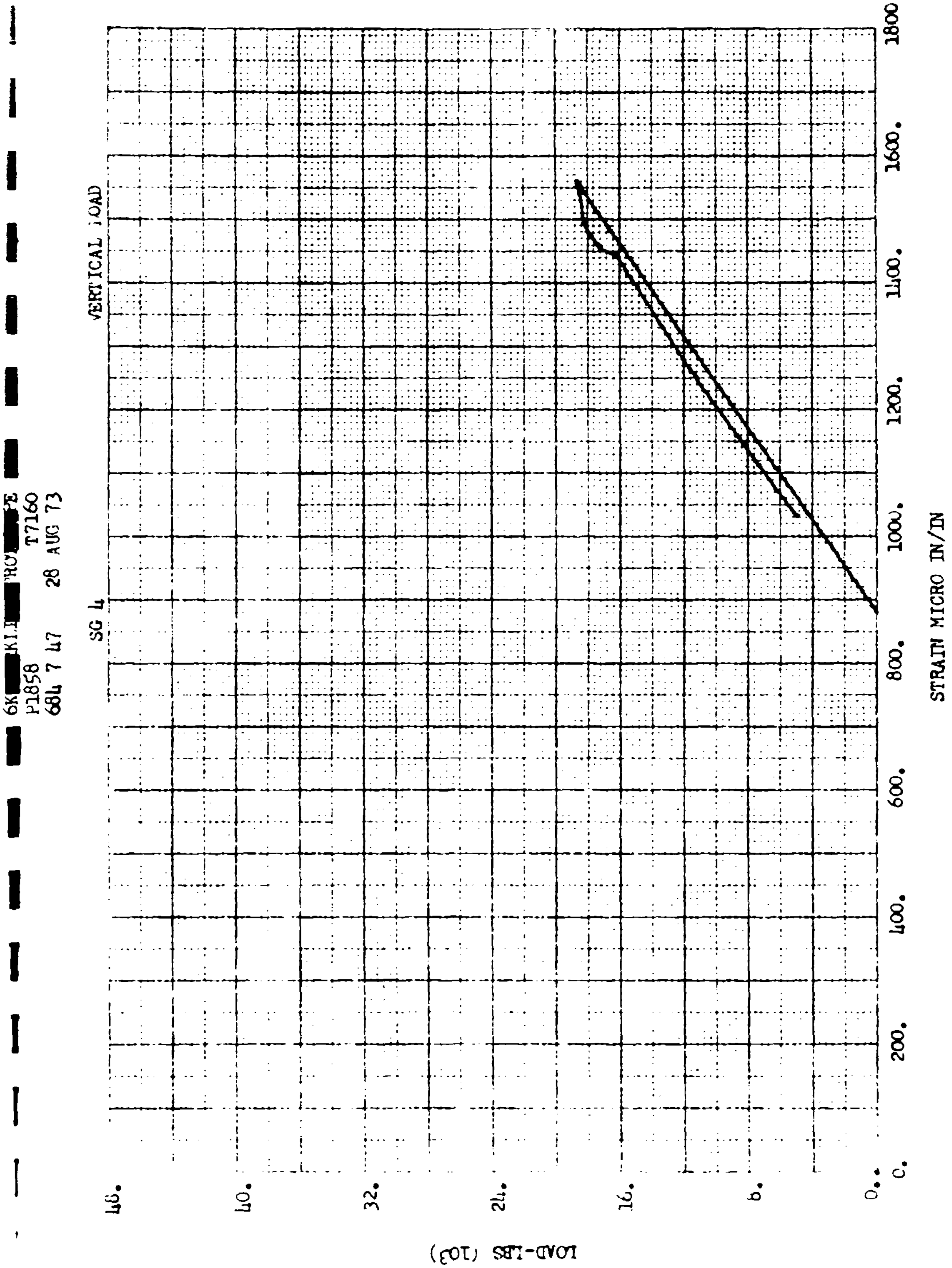
PLOTS OF STRAIN VERSUS LOAD

DURING VERTICAL LOADING

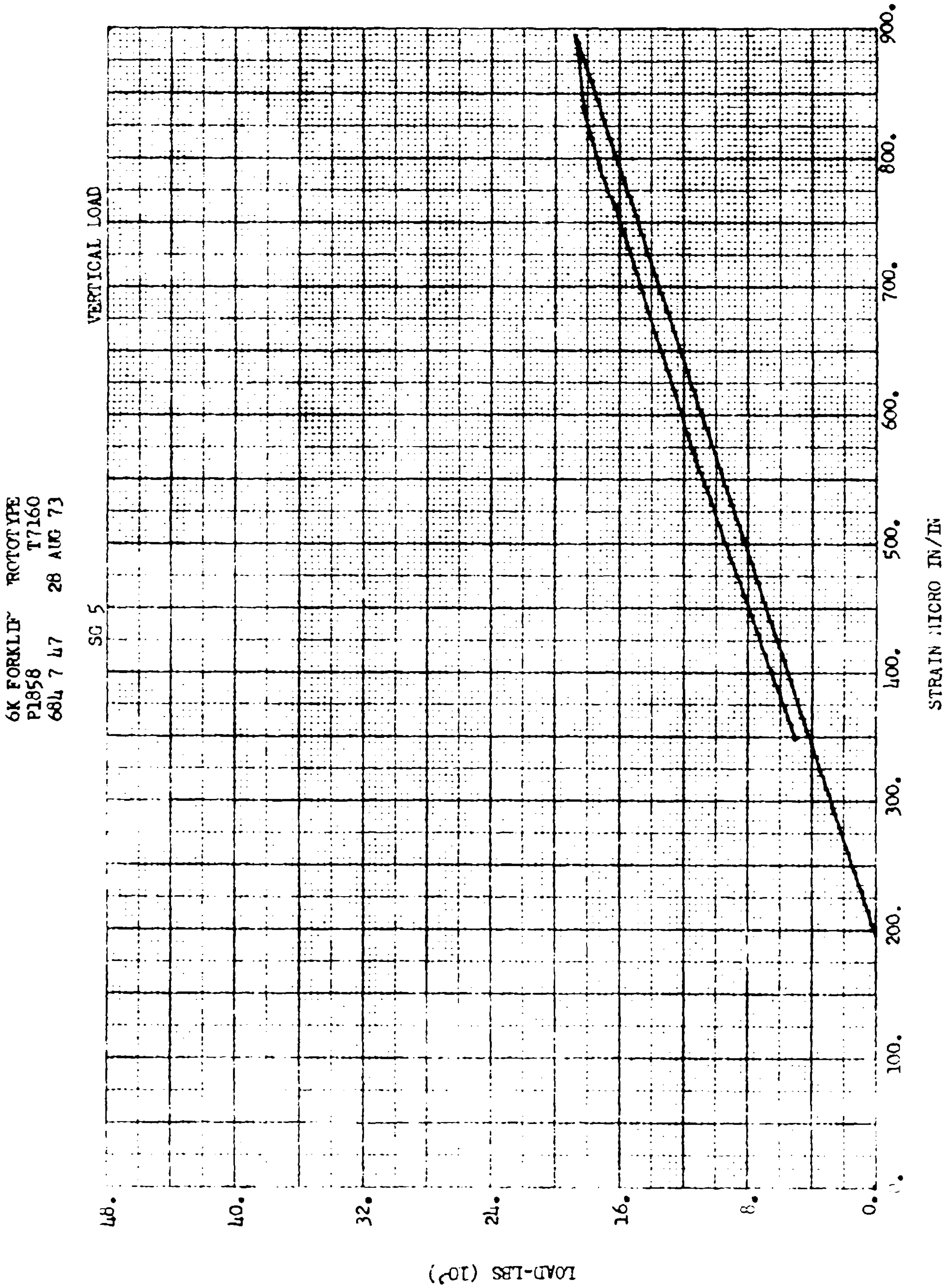

6K FORKLIF PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 1
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
0.
8.
16.
24.
32.
40.
48.

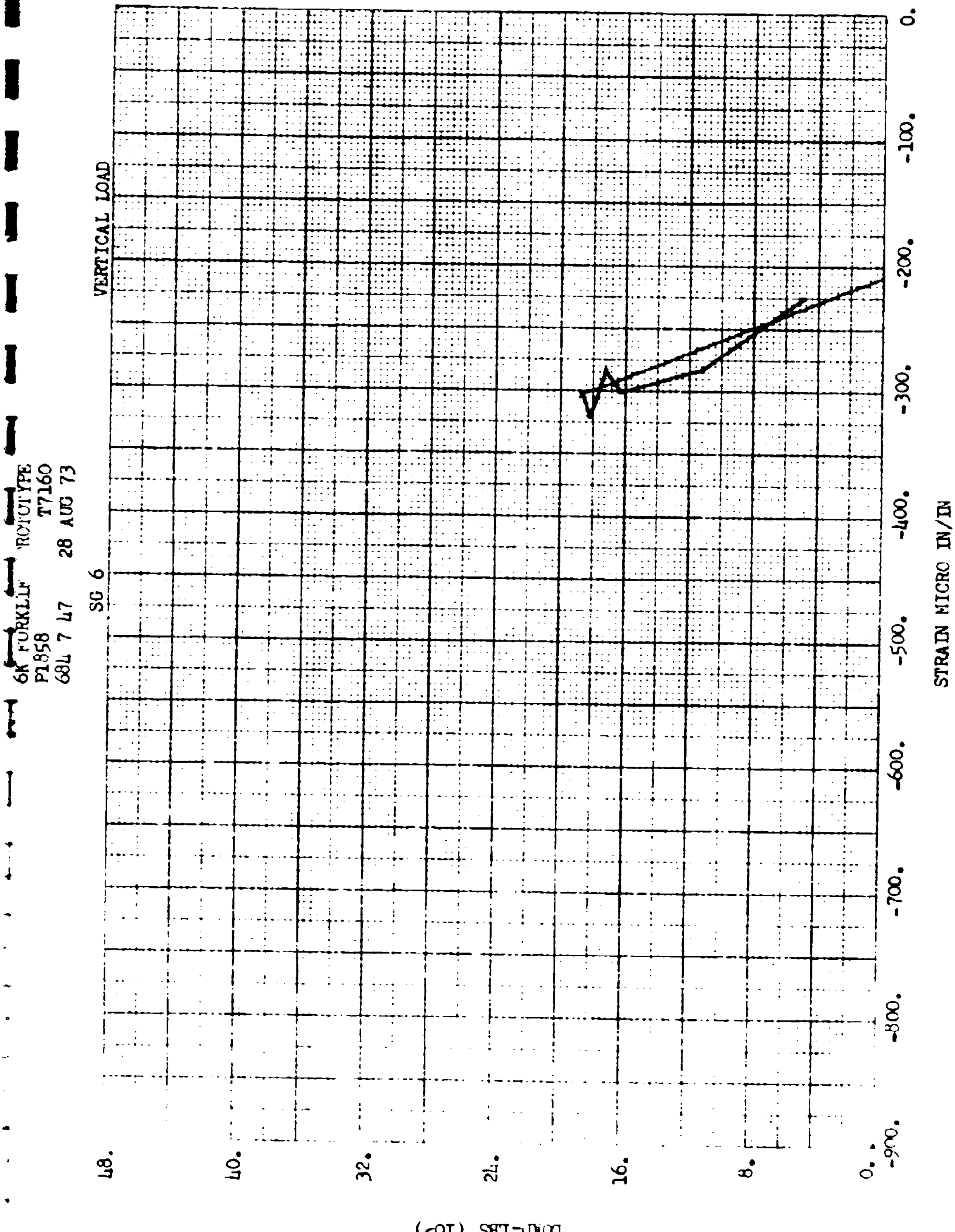

P1858
684 7 47
T7160
28 AUG 73
SG 2
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.
3600.
0.
8.
16.
24.
32.
40.
48.

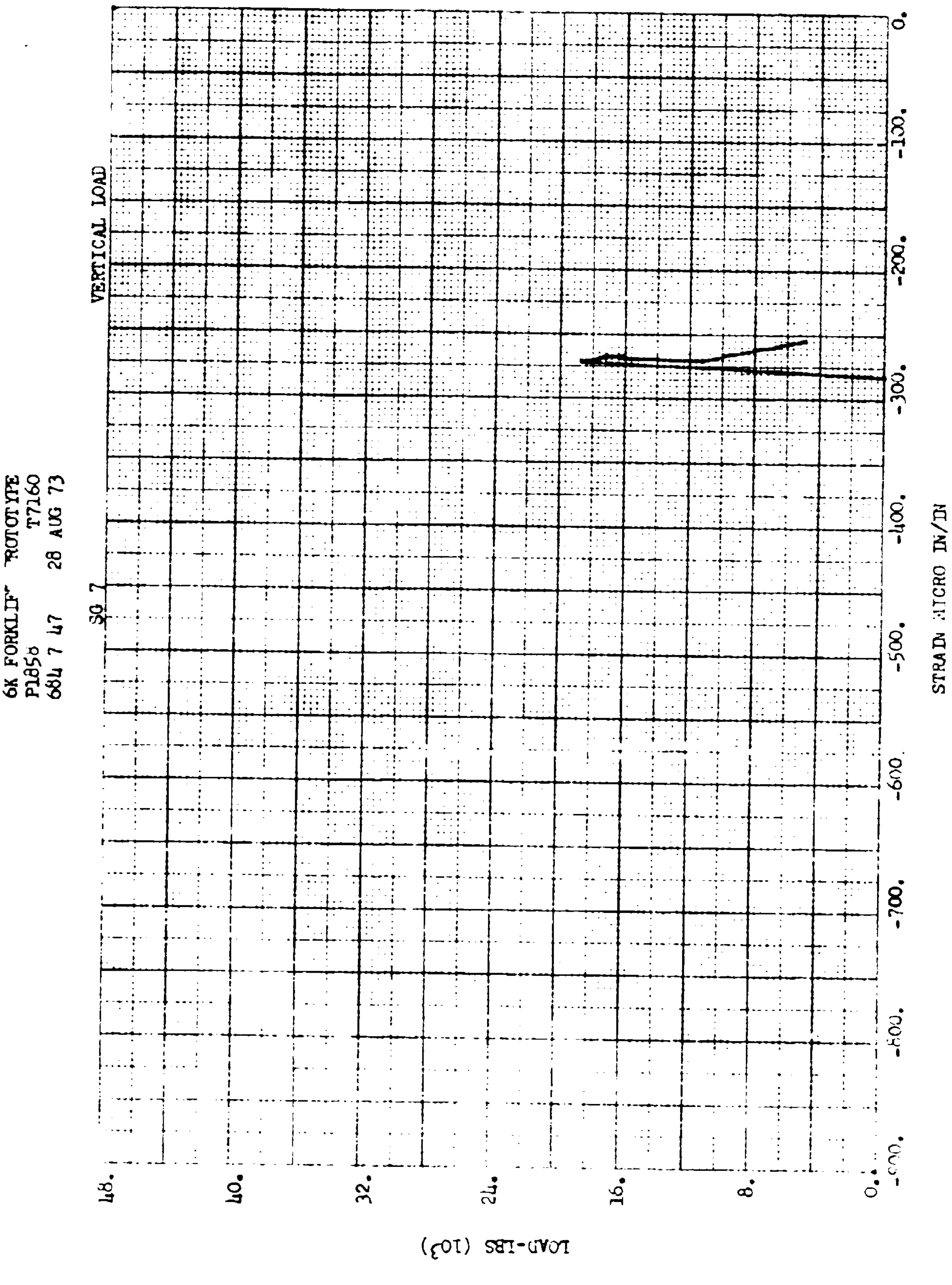

6K FORKLIF PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 3
VERTICAL LOAD
STRAIN MICRO IN/IN
0. 100. 200. 300. 400. 500. 600. 700. 800. 900.
LOAD-LBS
0. 8. 16. 24. 32. 40. 48.

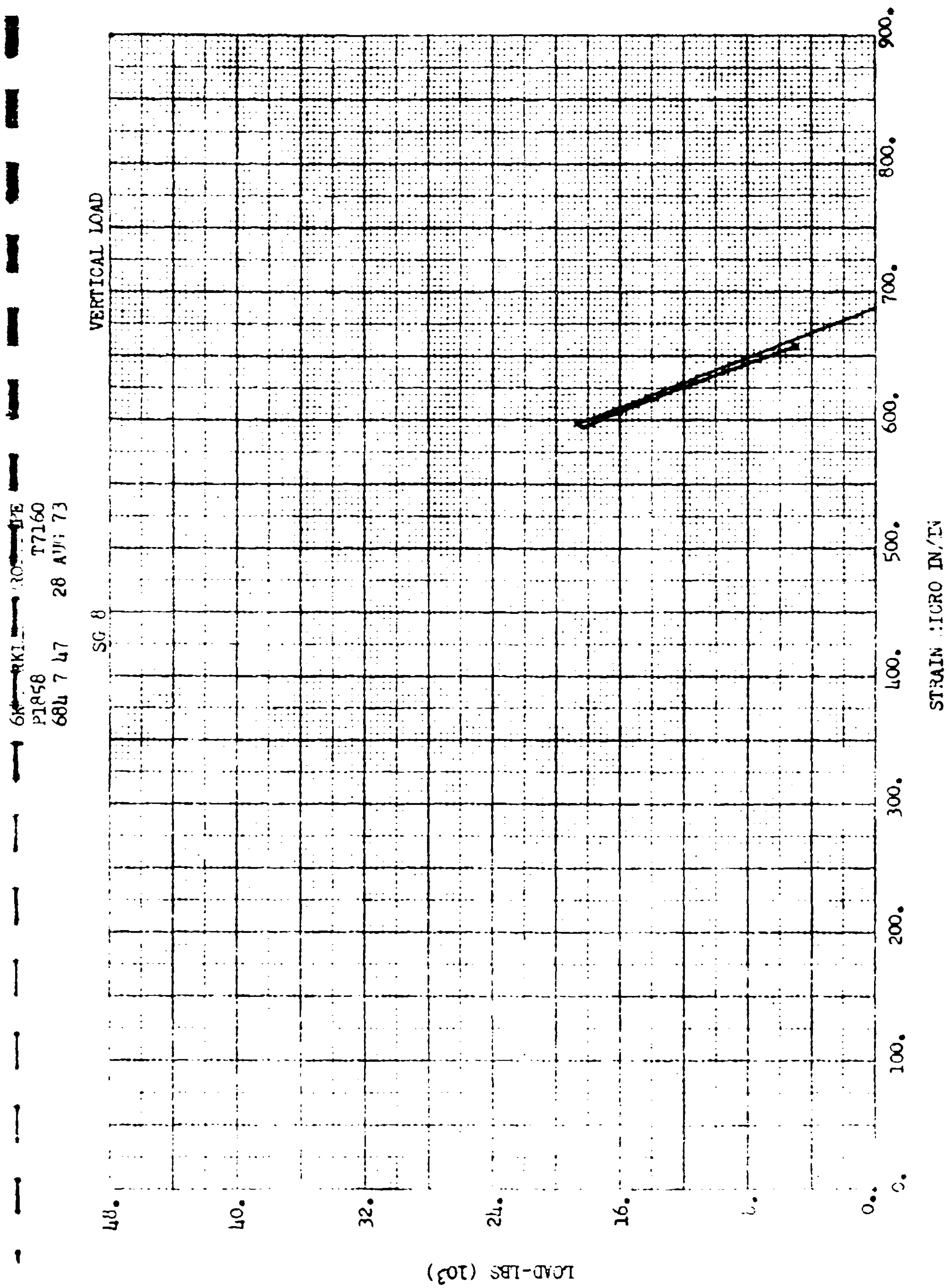

6K [redacted] KI [redacted] PRO [redacted] E
P1858 T7160
684 7 47 28 AUG 73
SG 4
VERTICAL LOAD
STRAIN MICRO IN/IN
0. 200. 400. 600. 800. 1000. 1200. 1400. 1600. 1800.
LOAD-LBS (10^3)
0. 8. 16. 24. 32. 40. 48.

[redacted]

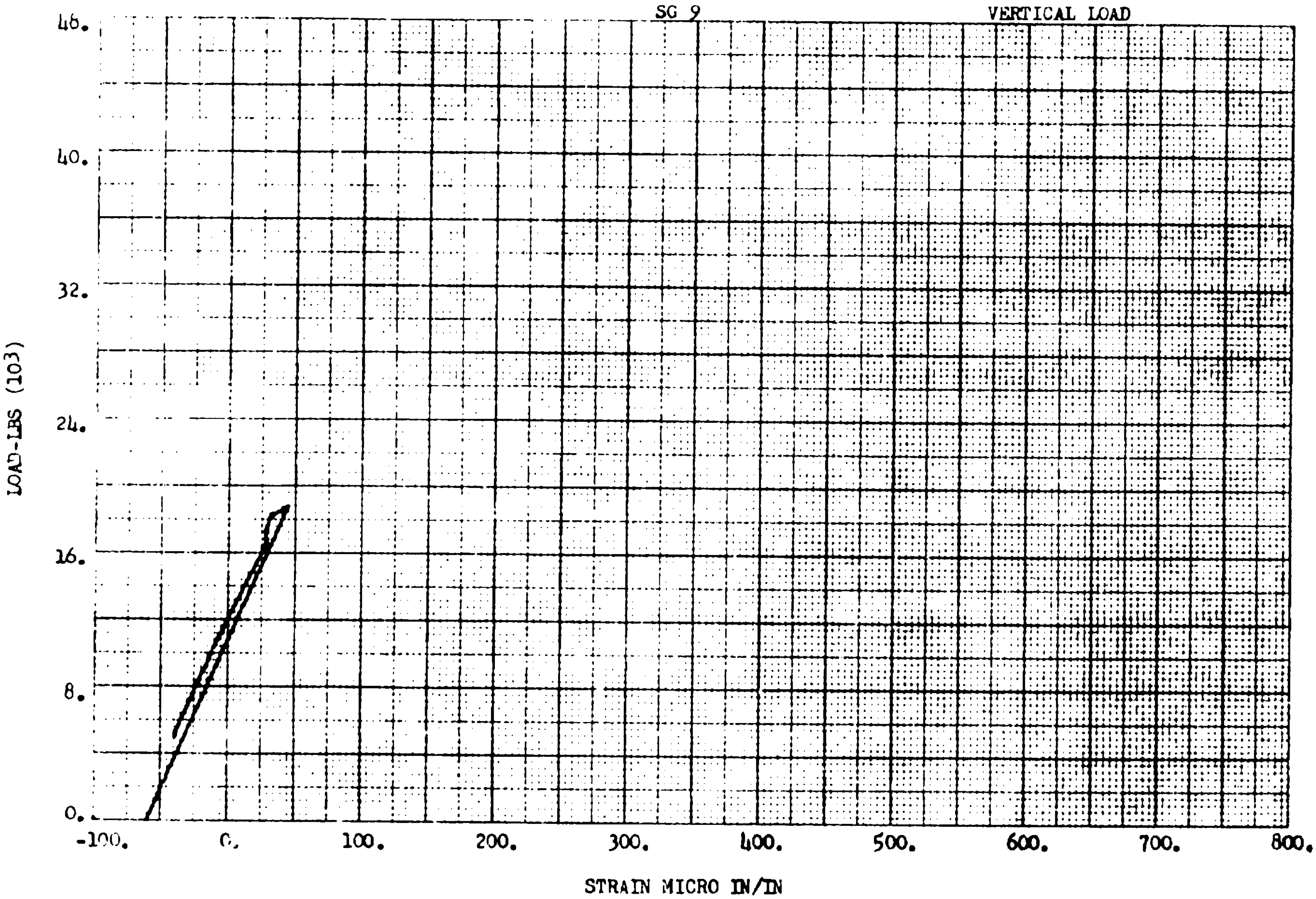

6K FORKLIF PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 5
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
0.
8.
16.
24.
32.
40.
48.

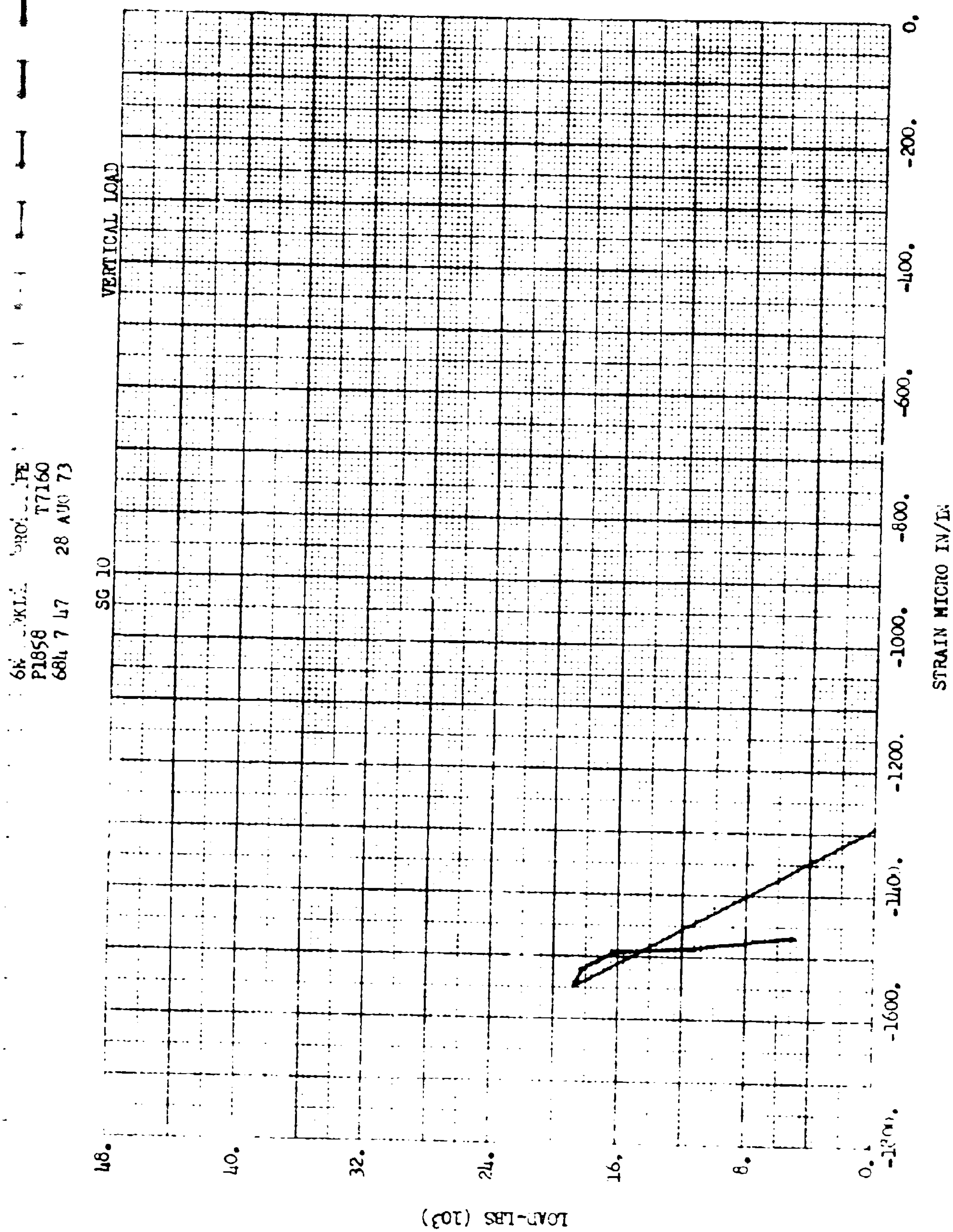

6K FORKLIF PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 6
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
-900.
0.
8.
16.
24.
32.
40.
48.


6K FORKLIFT PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
30.7
VERTICAL LOAD
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
-900.
STRAIN MICRO IN/IN
48.
40.
32.
24.
16.
8.
0.
LOAD-LBS (10³)


VERTICAL LOAD
P1858
684 7 47
T7160
28 AUG 73
SG 8
STRAIN MICRO IN/IN
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
LOAD-LBS (10³)
0.
16.
24.
32.
40.
48.

6K FORKLIF' PROTOTYPE
P1858 T7160
684 7 47 28 AUG 73




P1858 T7160
684 7 47 28 AUG 73
SG 10
VERTICAL LOAD
STRAIN MICRO IN/IN
0.
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-400.
-600.
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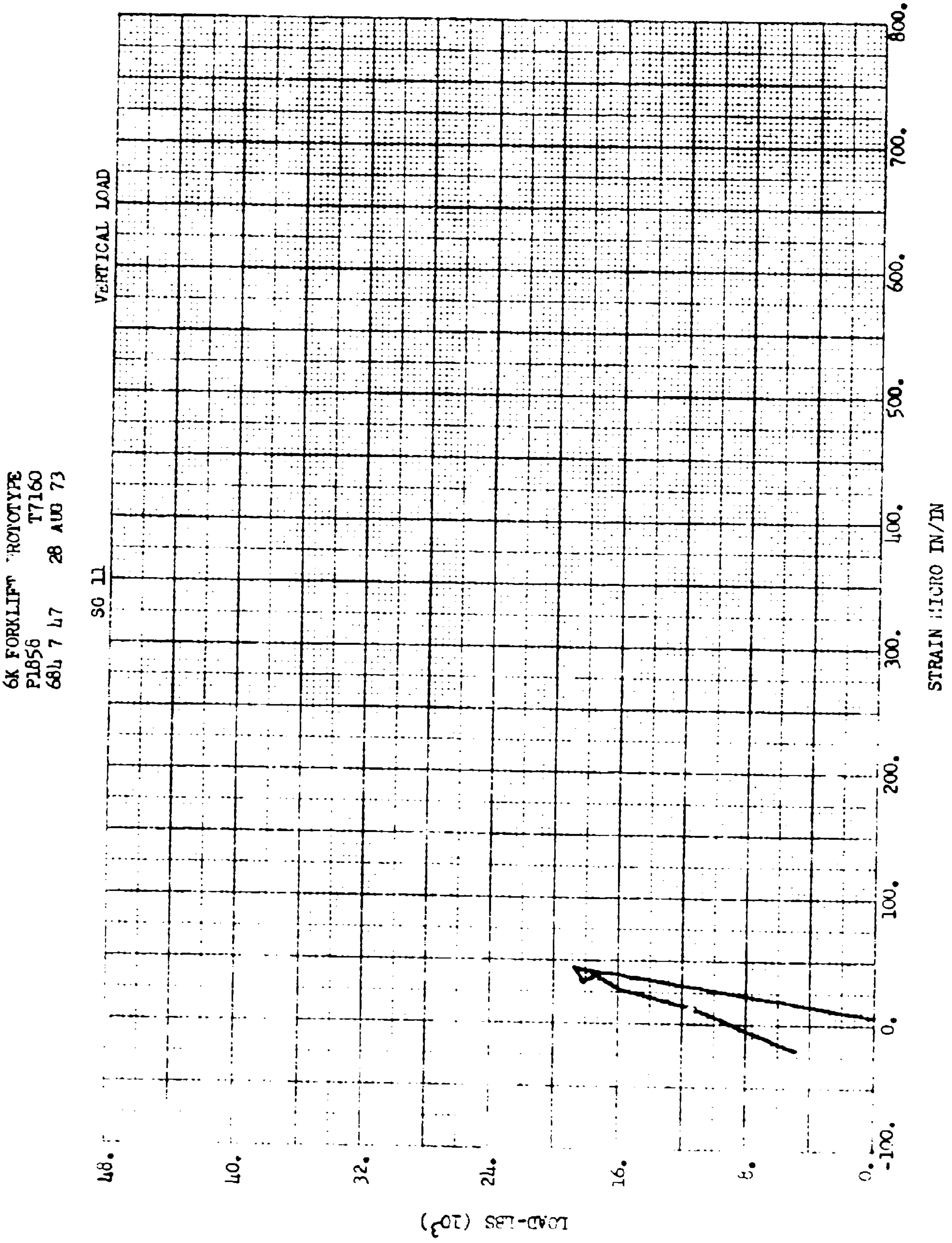
-1000.
-1200.
-1600.
LOAD-LBS (10³)
48.
40.
32.
24.
16.
8.
0.


6K FORKLIFT PROTOTYPE
P1856 T7160
684 7 47 28 AUG 73
SG 11
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
-100.
0.
100.
200.
300.
400.
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600.
700.
800.
0.
8.
16.
24.
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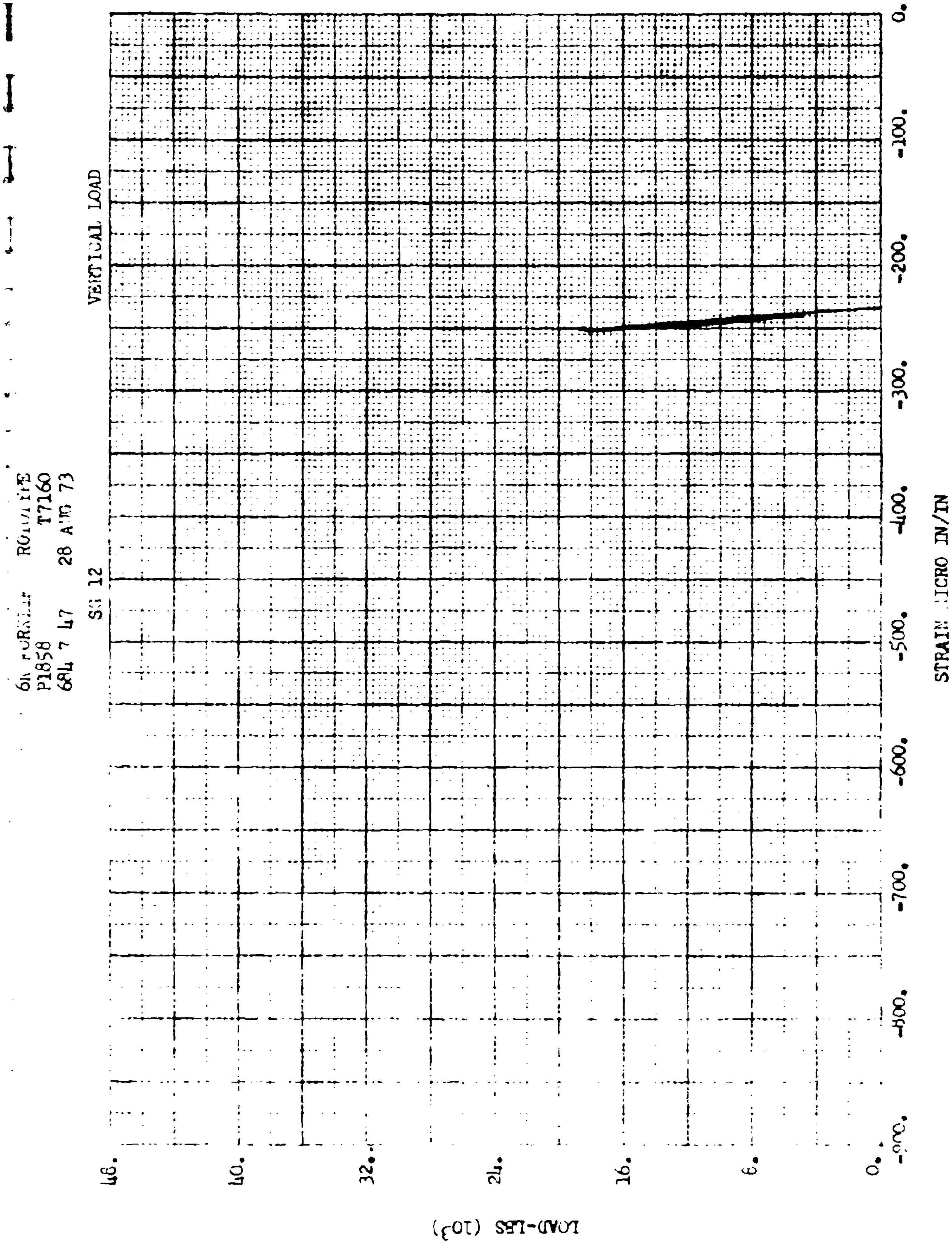
40.
48.


VERTICAL LOAD
P1858
T7160
SG 12
STRAIN MICRO IN/IN
LOAD-LBS (10^3)
0.
-100.
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-600.
-700.
-800.
48.
40.
32.
24.
16.
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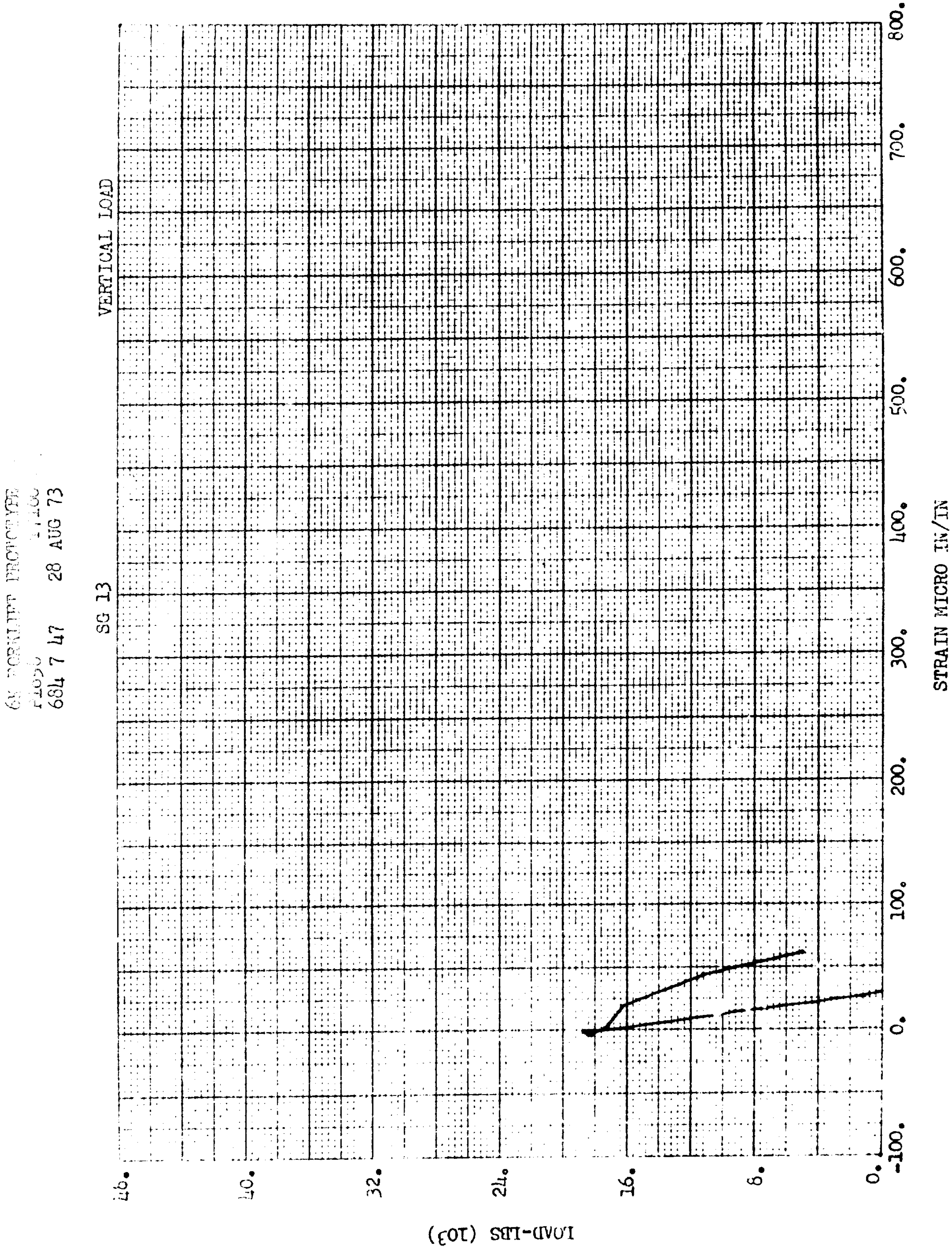
684 7 47
28 AUG 73
SG 13
VERTICAL LOAD
STRAIN MICRO IN/IN
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0.
100.
200.
300.
400.
500.
600.
700.
800.
LOAD-LBS (103)
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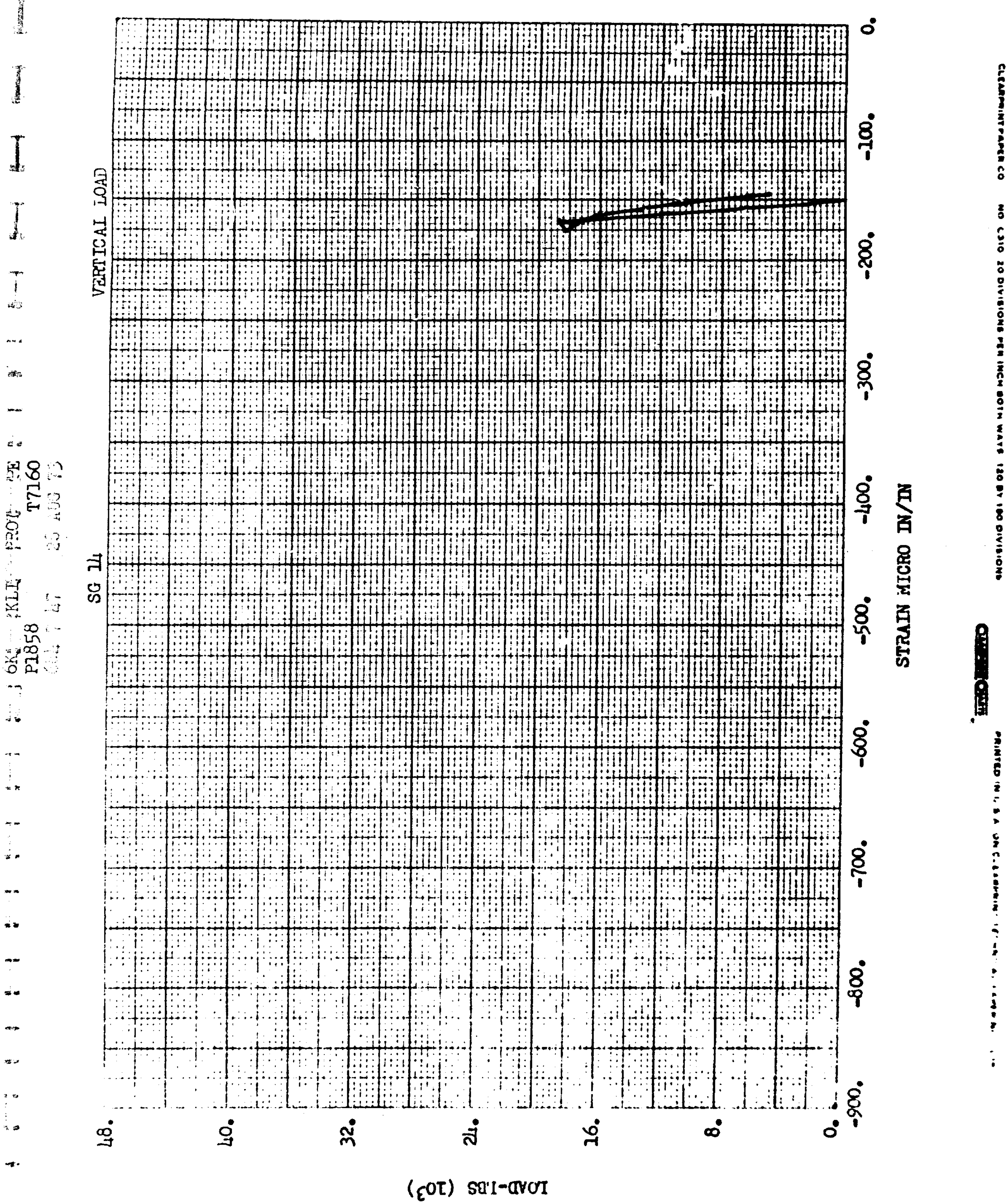
16.
24.
32.
40.
48.


VERTICAL LOAD
SG 14
P1858
T7160
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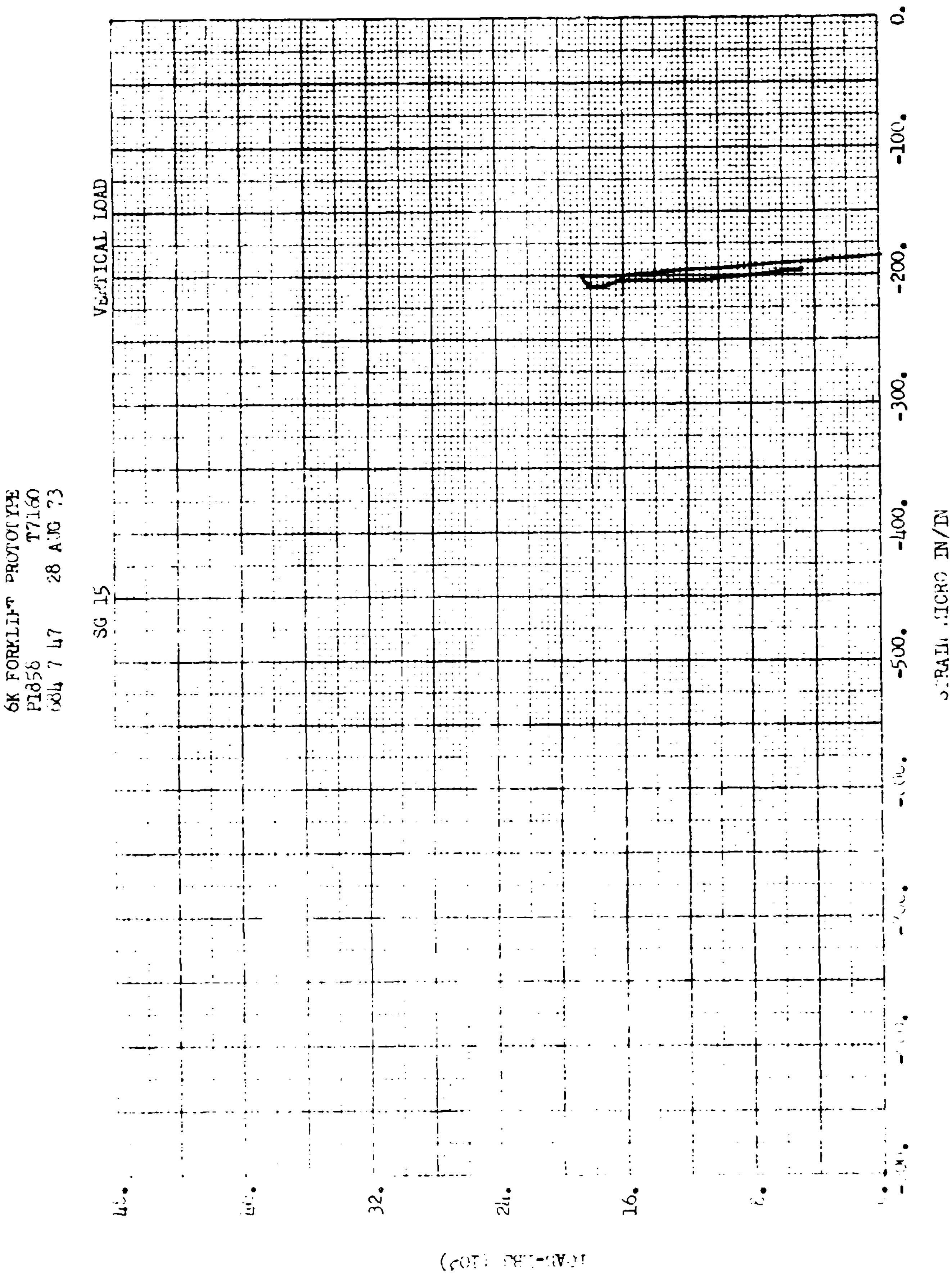
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
-900.
STRAIN MICRO IN/IN
48.
40.
32.
24.
16.
8.
0.
LOAD-LBS (10³)


6K FORKLIFT PROTOTYPE
P1856 T7160
684 7 47 28 AUG 73
SG 15
VERTICAL LOAD
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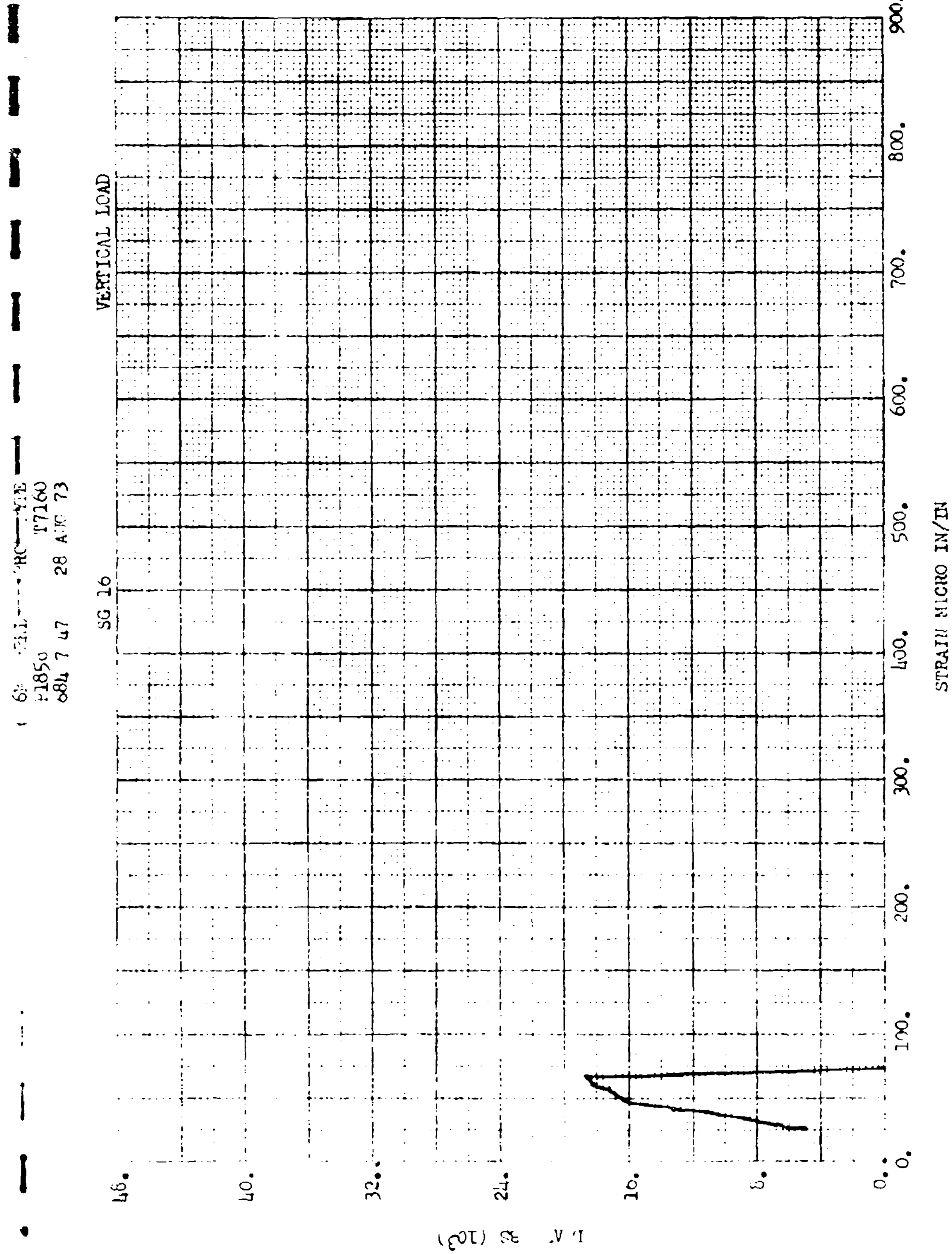
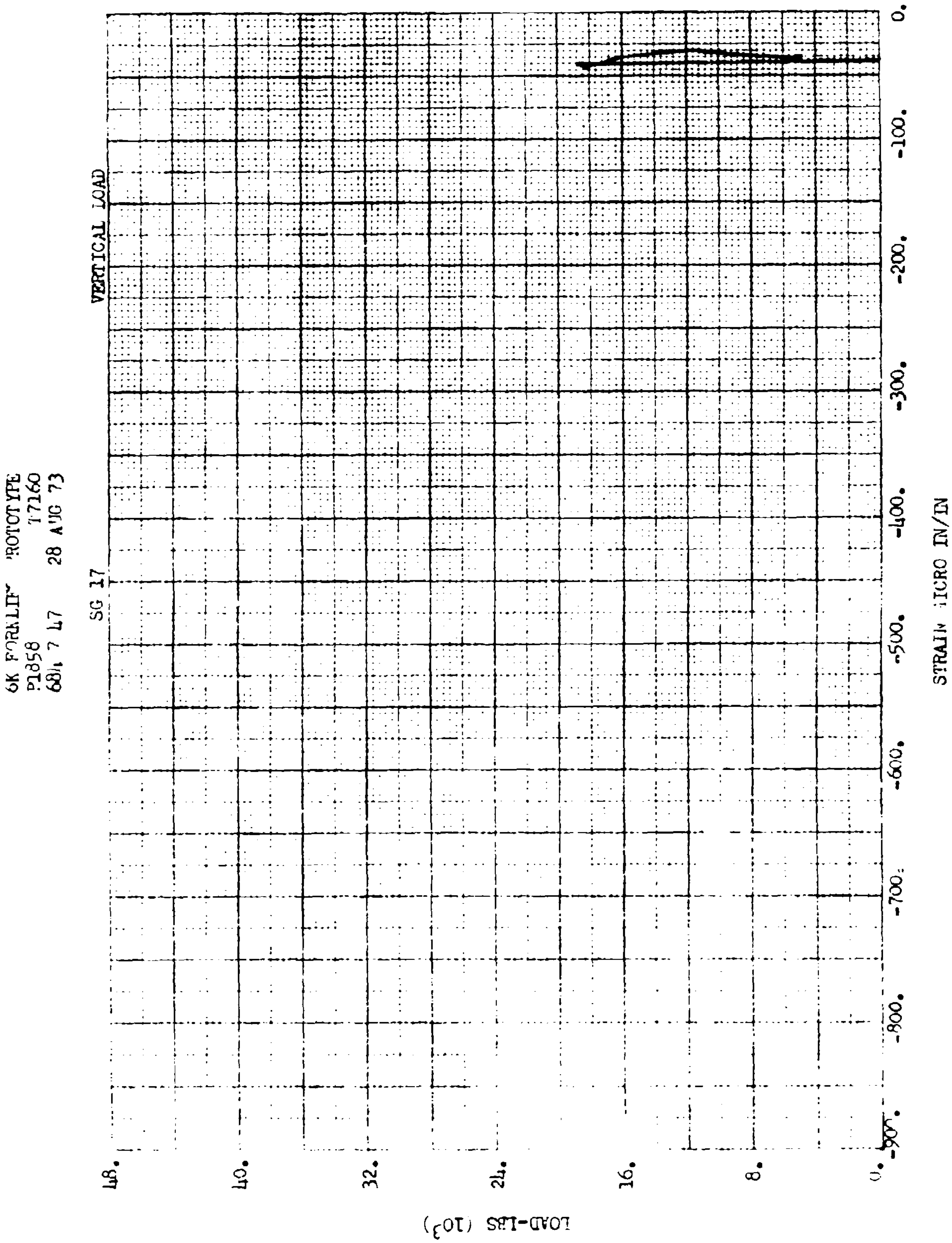
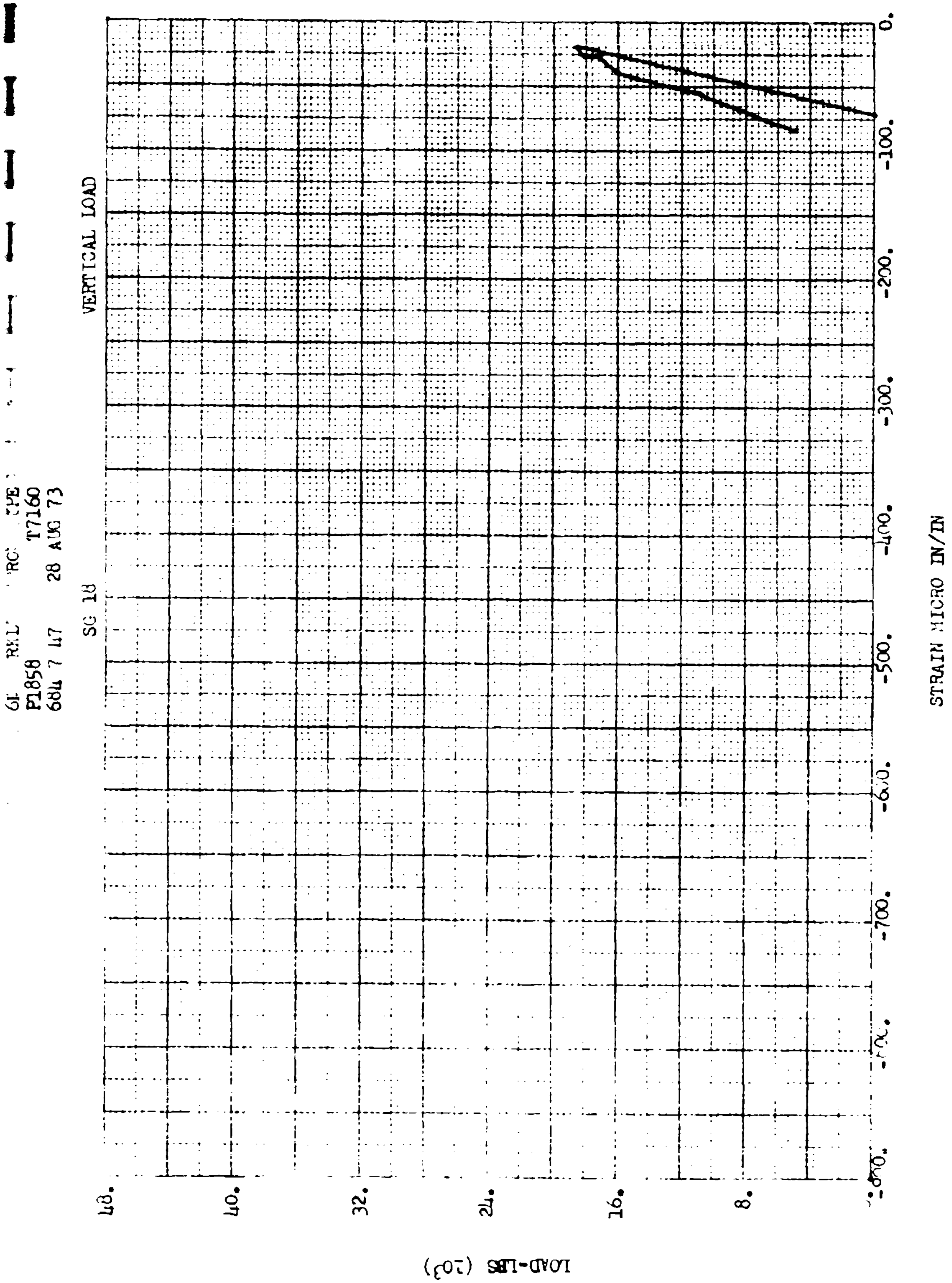
-300.
-400.
-500.
32.
24.
16.


VERTICAL LOAD
SG 16
P1850
684 7 47
T7160
STRAIN MICRO IN/IN
0.
100.
200.
300.
400.
500.
600.
700.
800.
900.
0.
8.
16.
24.
32.
40.
48.


6K FORKLIFT PROTOTYPE
P1858 T7160
28 AUG 73
SG 17
VERTICAL LOAD
STRAIN MICRO IN/IN
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
-900.
LOAD-LBS (10^3)
48.
40.
32.
24.
16.
8.
0.


P1858 T7160
28 AUG 73
SG 18
VERTICAL LOAD
STRAIN MICRO IN/IN
LOAD-LBS (10³)
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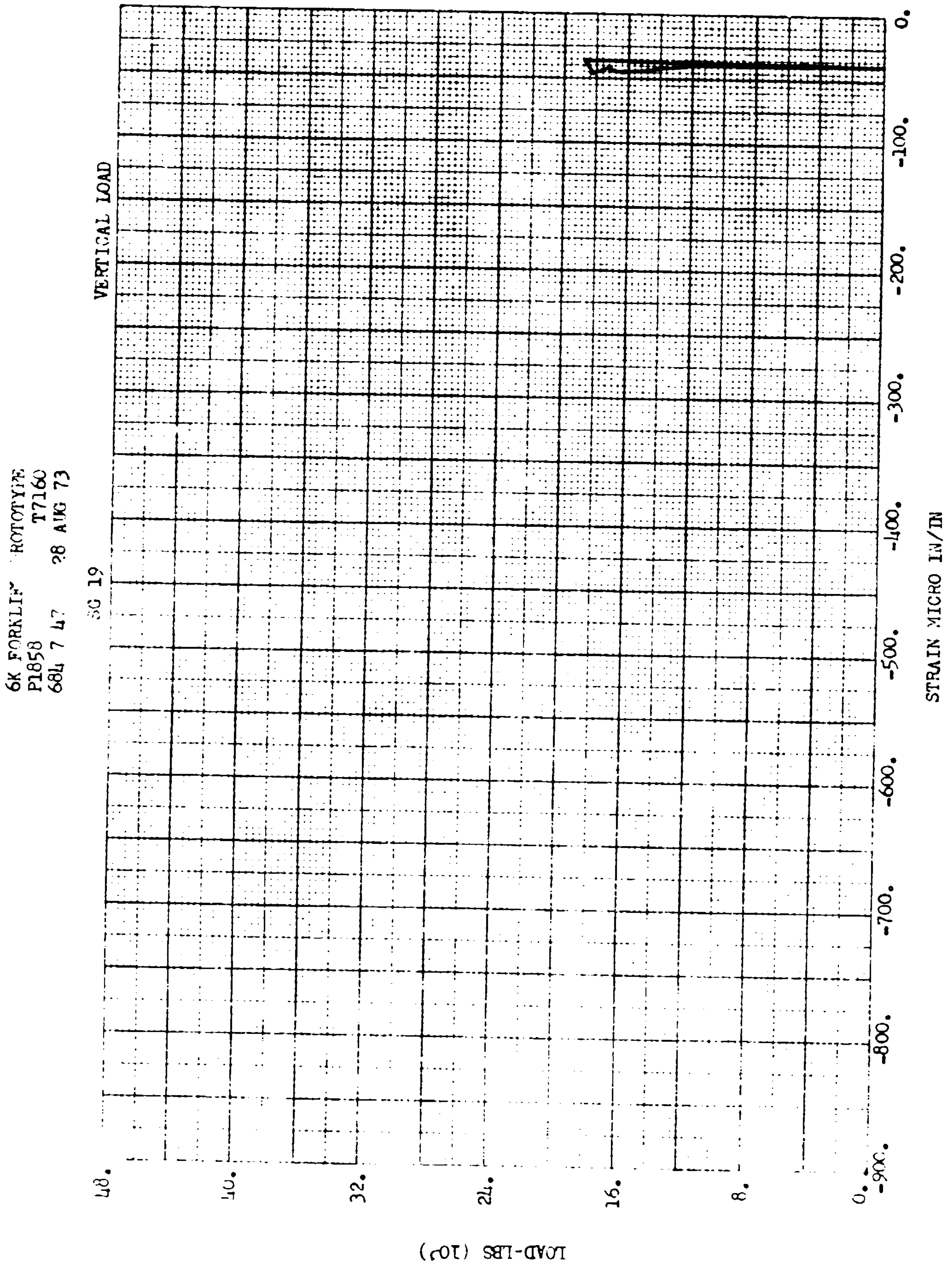
-300.
-400.
-500.
-700.
48.
40.
32.
24.
16.
8.


6K FORKLIF ROTOTYPE
P1858 T7160
684 7 47 28 AUG 73
SG 19
VERTICAL LOAD
STRAIN MICRO IN/IN
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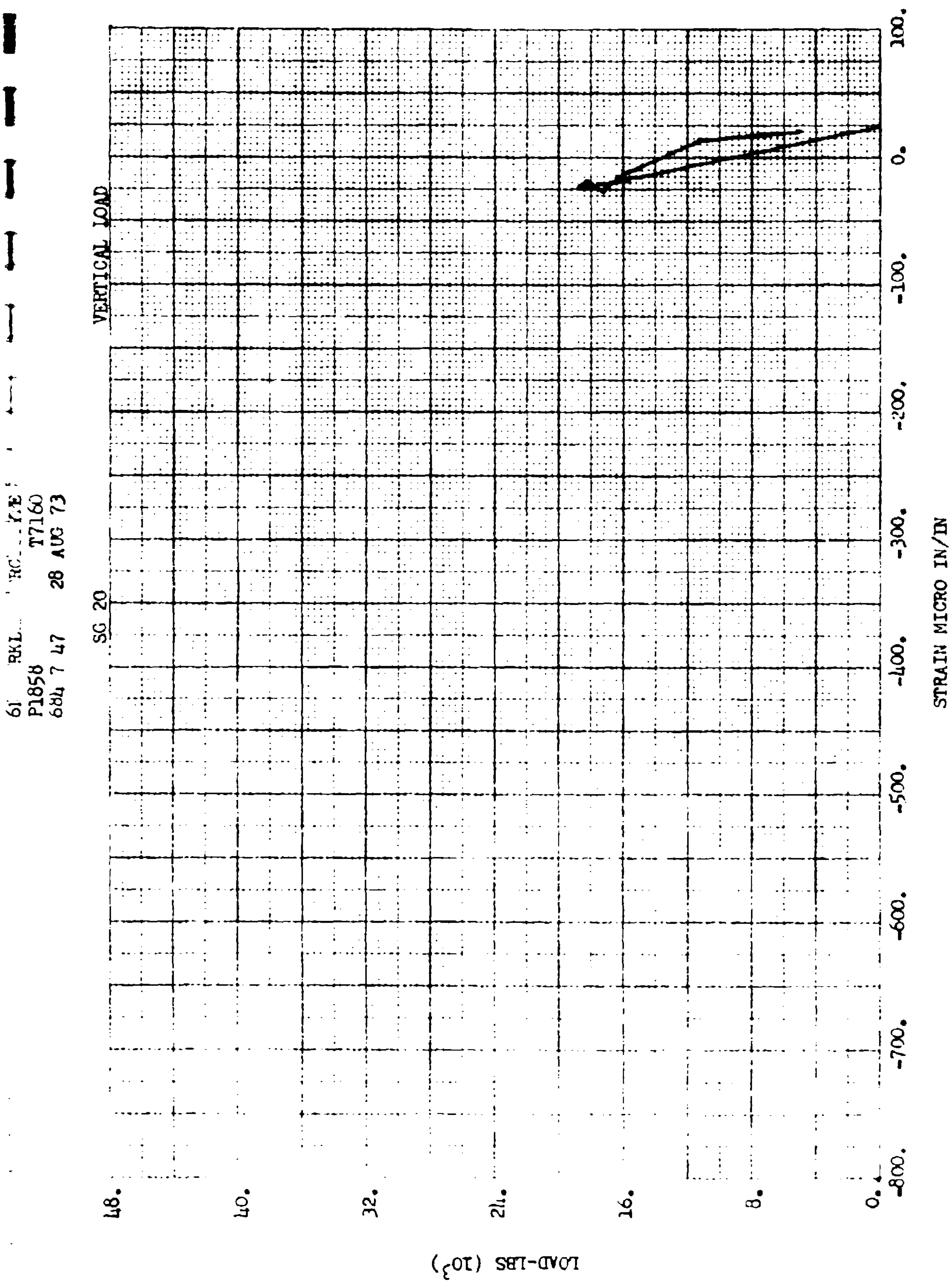
-200.
-300.
-400.
-500.
-600.
-700.
-800.
-900.
LOAD-LBS (10³)
48.
40.
32.
24.
16.
8.
0.


P1858
684 7 47
T7160
28 AUG 73
SG 20
VERTICAL LOAD
STRAIN MICRO IN/IN
100.
0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
-800.
LOAD-LBS (10^3)
48.
40.
32.
24.
16.
8.
0.

APPENDIX 6.7

ANALYSIS OF PROTOTYPE TEST RESULTS

6K ROPS - TEST DATA REDUCTION

A comparison of predicted side load to test side load is shown on Page 4. A comparison of predicted vertical load to test vertical load is shown on Page 5. The vertical load prediction might be considered to be reasonably accurate, except the test curve breaks at 23,000 lbs rather than at 16,000 lbs as predicted. This is probably due to high material yield strength. Actual material properties are not available at this time since the ROPS is being considered for reuse for a rollover test.

The side load prediction does not agree well with the test curve. Following is the reduction of the side load test data for the purpose of determining the reason for the difference between the predicted side load curve and test side load curve.

SIDE LOAD TEST DATA REDUCTION

Sketch, Page 6 shows the location of deflection gages for the side load test conducted on 28 August 1973. Deflections obtained from the test are given in Page 7. It was observed that side load deflection results did not agree well with predicted values; therefore a supplemental side load test was run on 29 August 1973 to obtain additional data to help determine the reason for the difference between predicted and actual side load curves. Deflection gage locations for the supplemental test are shown on pages 8 and 9 and test data is given on page 10. FS S7 and NS S7 correspond with 4S and 3S, page 6.

Before investigating the difference between the predicted and test side load curves, the history of the 6K ROPS predictions and tests has to be reviewed. The graph on page 11 shows the significant curves from the 6K ROPS program.

Curve 1 and curve 2 , from 6K ROPS PDR 4 April 73 page 36, are computer predictions for the ROPS side load test run 28 May 1973. Curve 1 is for a ROPS model with the lower end of the vertical legs pinned in bending. Curve 2 is for a ROPS model with the lower end of the vertical legs fixed. Curve 1 (pinned) has always been felt to be most accurate in the small deflection range because, for small deflections, clearance and the rubber/cloth isolators allow the ROPS foot to rotate in the socket. Curve 2 (fixed) would be the most accurate curve in the large deflection range, because for large deflections, the ROPS feet make contact in the socket and develop moment capability. Even though curve 2 was not expected to be accurate in the small deflection range it was used as the prediction curve because it was expected to predict the correct maximum load. And, at that time, the computer program did not have the capability to transition from a pinned end to fixed end fixity.

Curve 3 from 6K ROPS PDR 4 April 73 page 35, is the prediction for the ROPS side load test run 29 May 1973 based on the CAT/CLARK ROPS bedplate test and obtained by conventional analysis.

Curve 4 is the actual side load test curve from test run 29 May 1973, reference 684-MLPR-12, TR-684-059, page 12.

Based on the test run 29 May 1973, a prediction curve, curve 5, was developed for the side load test run 28 August 1973, reference 6K ROPS CDR dated 23 July 1973, page 12. The elastic properties of the redesigned ROPS were very similar to the original ROPS therefore the same initial slope was predicted as obtained from the first test, curve 4. The maximum load was increased by conventional analysis methods for the decreased length of the upright ROPS tubes.

Curve 6 is the actual side load test curve from the test run on 28 August 1973, reference page 7.

The primary point to be brought out by comparing these curves is the importance of the foot socket clearance to overall ROPS stiffness. The original conventional analysis prediction, curve 3, was based on the CAT/CLARK bedplate test which had a conventional rectangular socket. This curve is very close to a pinned end ROPS configuration, curve 1. The actual test, curve 4, produced a much more rigid elastic curve than predicted by the CAT/CLARK bedplate test. This can now be contributed to the very rigid semi-conical foot/socket design used on the first 6K ROPS test. Proof of this effect is that curves 1, 3, and 6 which all have large clearance, rectangular sockets all have similar slopes in range R.

Since the second 6K ROPS tested incorporates a rectangular, large clearance foot/socket configuration, the prediction curve should have been curve 3 used for the first test but modified for curve 5 maximum load value due to shorter ROPS tubes. The resulting composite curve, curve 7 is practically identical to the second 6K ROPS test side load curve, curve 6, except for the flat offset between 0.0 and 2.0 inches obtained from the test. The only remaining discrepancy between the test and the corrected analytical curve then, is the flat initial offset at less than two inches deflection obtained from the test. Following is the reduction of test data to determine the cause of this initial flat offset.

Both computer and conventional side load vs. deflection analysis approaches assume the ROPS vertical legs are held from twisting in the socket (fixed for torsion). If the ROPS vertical legs are actually rotating in the sockets, analysis indicates a considerable reduction in elastic stiffness would result. The table on Pg. 12 reduces test data to determine the amount of rotation at the ROPS feet compared to the ROPS roof, and tabulates the amount of ROPS torsional fixity obtained during the test. Next, the table modifies the ROPS torsional spring rate, K_{TOR}, developed in "ROPS Load vs. Deflection Calculation", Page 13. Using the modified spring rate, K'_{TOR}, the modified ROPS deflection, $\sum\delta'$ is obtained. Each value of $\sum\delta'$ obtained is an equation for the load/deflection curve. Therefore when the slope of each equation, m is obtained, a continuous curve can be plotted. Plotting the slope from 0.0 deflection from 0.0 to 1.0 inches, slope from 2.0 inch deflection from 1.0 to 3.0 inches, slope from 4.0 inch deflection from 3.0 to 5.0 inch, etc, and adding this plot to the bottom end of the modified prediction curve (curve 7, page 14), curve 8, page 14 is obtained. The test curve, curve 6,

is repeated on page 14.

In summary, the good agreement between the two curves on page 14 indicates the differences between predicted and test side load curves is due to the larger socket clearance in the prototype 6K ROPS design.

A review of the strain gage data indicates material yielding in the ROPS vertical tubes and in the ROPS gussets at the upper end of the vertical tubes. Assuming ROPS tube F_{TY} = 55,000 psi,

$$\epsilon_{P.L.} = \frac{F_{TY}}{E} = \frac{55000}{29 \times 10^6} = 1900 \ \mu\text{in/in}$$

$$\epsilon_{Yield} = 1900\ \mu\ \text{in/in} + 2000\ \mu\ \text{in/in} = 3900\ \mu\ \text{in/in}$$

At required side load energy, strain gage 1 at 2400 μ in/in exceeded the material proportional limit and strain gage 2 at 3900 μ in/in reached material yield strength.

One of the two strain gages on the gussets recorded the highest strain in the test. At required side load energy, gage 8 and 10 developed 3860 μ in/in and -4750 μ in/in respectively. Assuming ROPS plate F_{TY} = 40,000 psi,

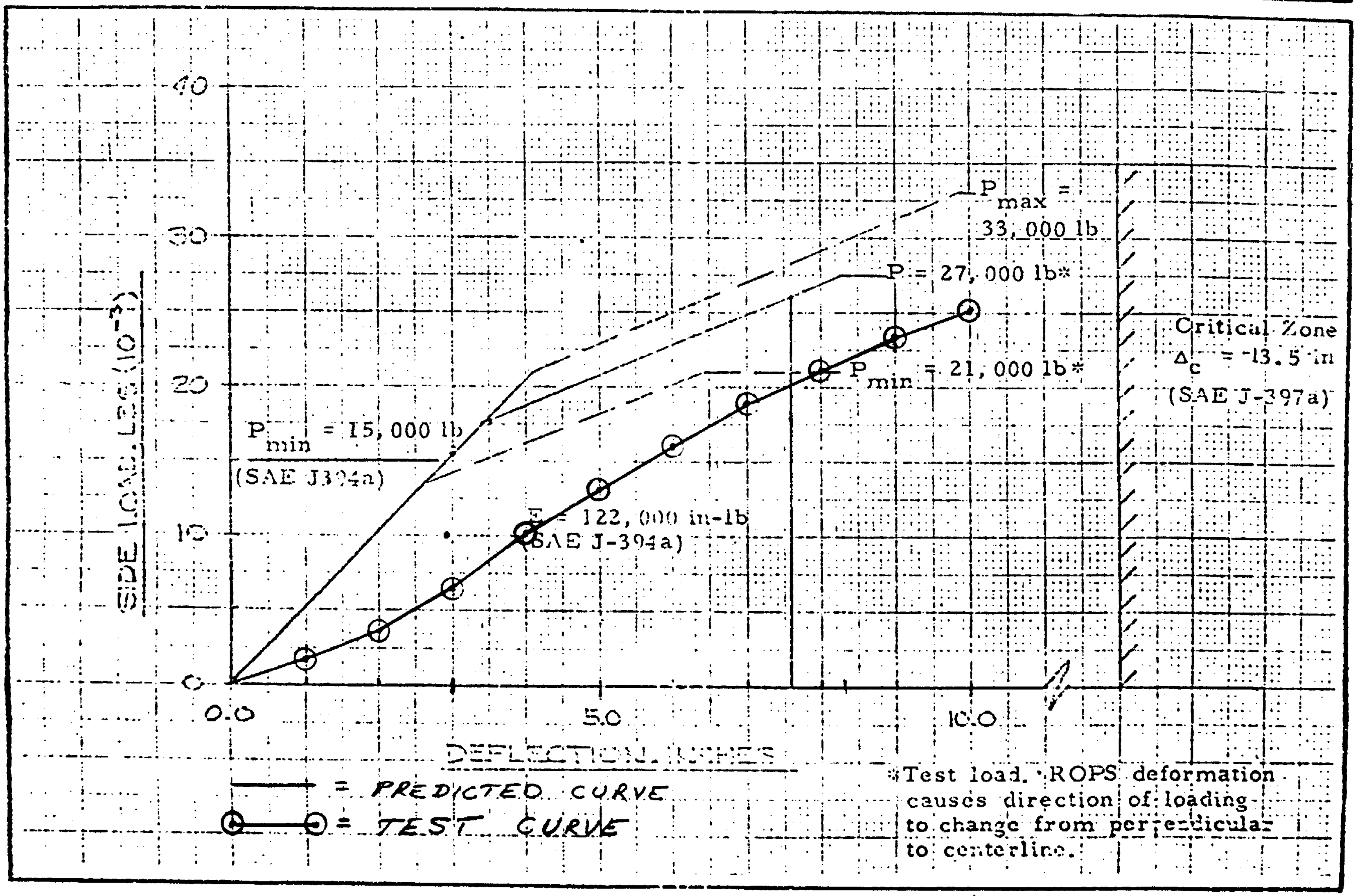
$$\epsilon_{P.L.} = \frac{40,000}{29 \times 10^6} = 1380\ \mu\ \text{in/in}$$

$$\epsilon_{Yield} = 1380 + 2000 = 3380\ \mu\ \text{in/in}$$

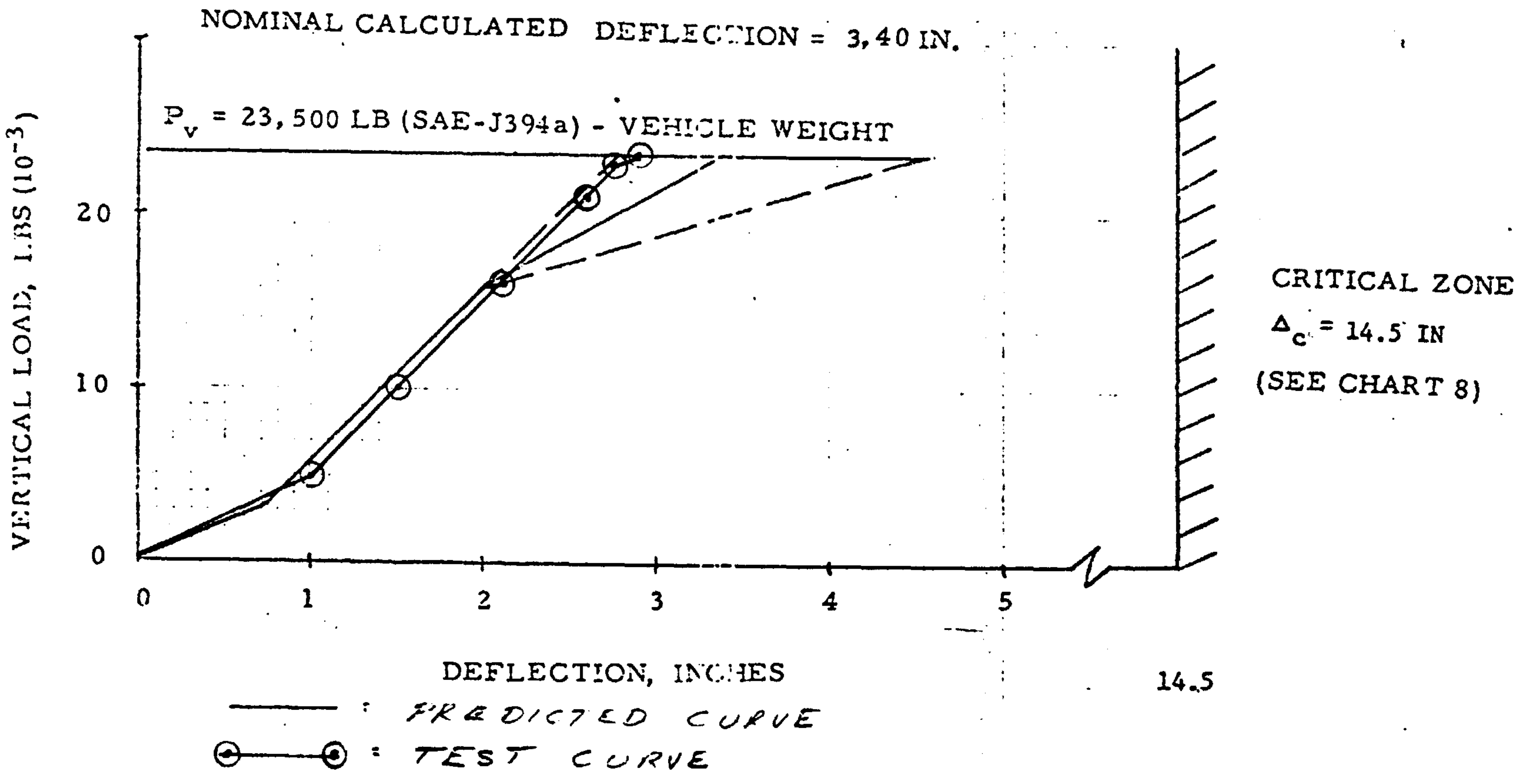
Both gages exceeded material yield strain of 3,380 μ in/in. However, from LPC Specification EMSD103, material elongation at failure is 20% or, 200,000 μ in/in. Therefore, the ROPS structure met required energy at

$$\frac{4750}{200,000} \times 100, \text{ or } 2\% \text{ of failure elongation.}$$

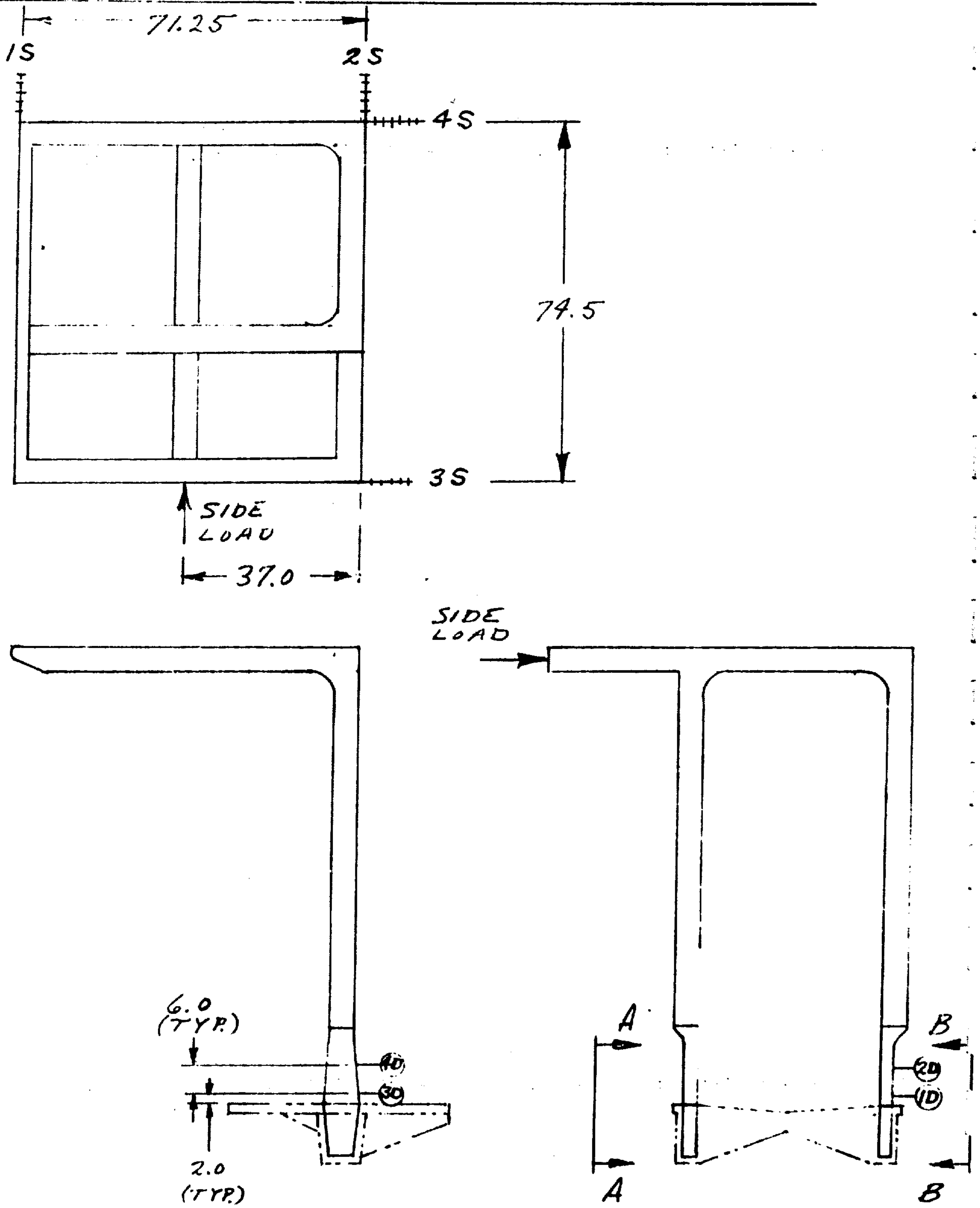
UDRC	6K ROPS CDR SIDE LOAD AND ENERGY ABSORPTION SUMMARY	CHART NO. 12 DATE 23 JULY 73



UPC	6K ROPS PDR VERTICAL LOAD SUMMARY	CHART NO. 11 DATE 23 JULY 73



6K ROPS - TEST DATA REDUCTION



LOCKHEED PROPULSION COMPANY
POTRERO TEST SERVICES

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K FORKLIFT - HORIZ LOAD TEST DATE 8/28/73

DEFL	LOAD	ENERGY	1-D	2-D	3-D	4-D	1-S	2-S	3-S	4-S			COMMENTS
ZERO	ZERO	ZERO	0.00	0.00	0.00	0.00	1.00	1.00	2.00	2.00			1-D - 2.5"
1.00	1797	886	.046	.065	.995	.993	2.10	1.[illegible]	1.60	2.41			2D · 6.5"
2.02	3995	3731	.099	.135	.991	.9[illegible]	3.45	1.75	1.25	2.9[illegible]			
3.00	6682	8806	.113	.161	.986	.978	4.76	2.12	0.77	3.45			NEW ZERO OF
4.00	10275	17250	.121	.179	.971	.951	6.15	2.50	0.04	3.80			4" DEFL
5.00	13346	29095	.123	.190	.926	.892	7.40	2.60	6.01	9.76			3-S = 7.00
6.00	16242	43907	.128	.204	.894	.839	8.72	2.90	5.10	9.91			4·S = 9.62
7.00	18998	61539	.137	.223	.855	.804	10.00	3.25	4.25	10.07			
8.00	21441	81725	.148	.245	.832	.770	11.35	3.60	3.35	10.20			
9.03	23639	104875	.162	.270	.817	.752	12.65	3.90	2.53	10.42			
10.00	25385	12868[illegible]	.176	.292	.806	.745	13.90	4.20	1.75	10.65			
3.48	ZERO	ZERO	.121	.167	.8[illegible]	.804	5.15	2.10	6.56	8.56			

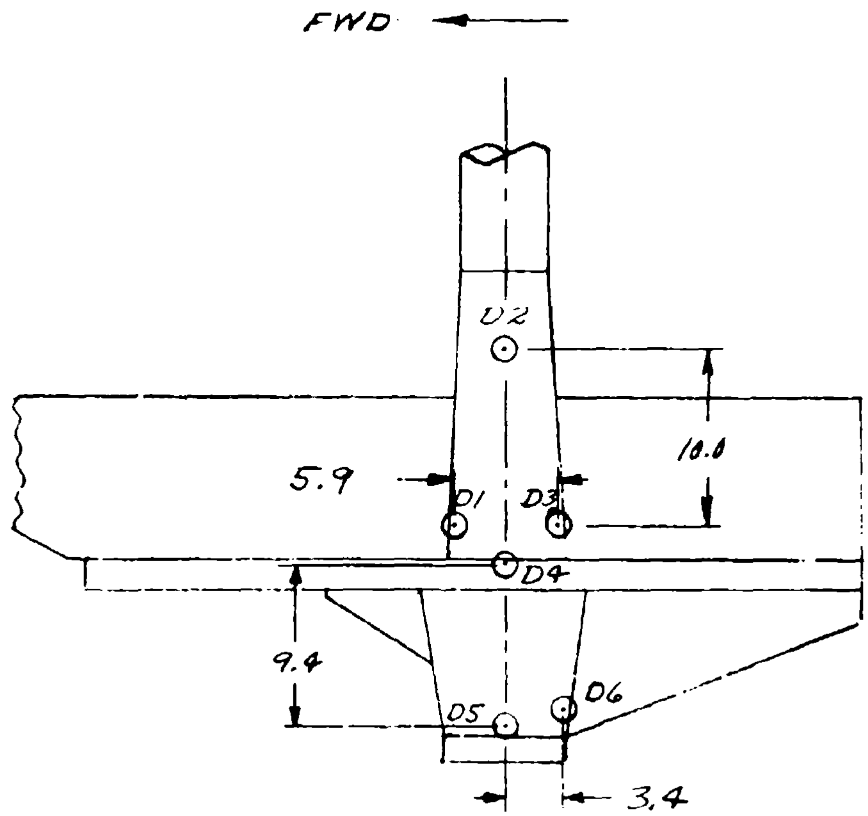
Prepared by: [stamp] 8/28/73 Approved by: ________

LOCKHEED PROPULSION CO.
REDLANDS, CALIFORNIA

PREPARED BY ZAHAREE		PAGE 8 OF
CHECKED BY		DATE 9/5/73
APPROVED BY		REPORT NO.

TITLE - SUB TITLE
6K ROPS- TEST DATA REDUCTION

VIEW A-A, NEAR SIDE (NS)

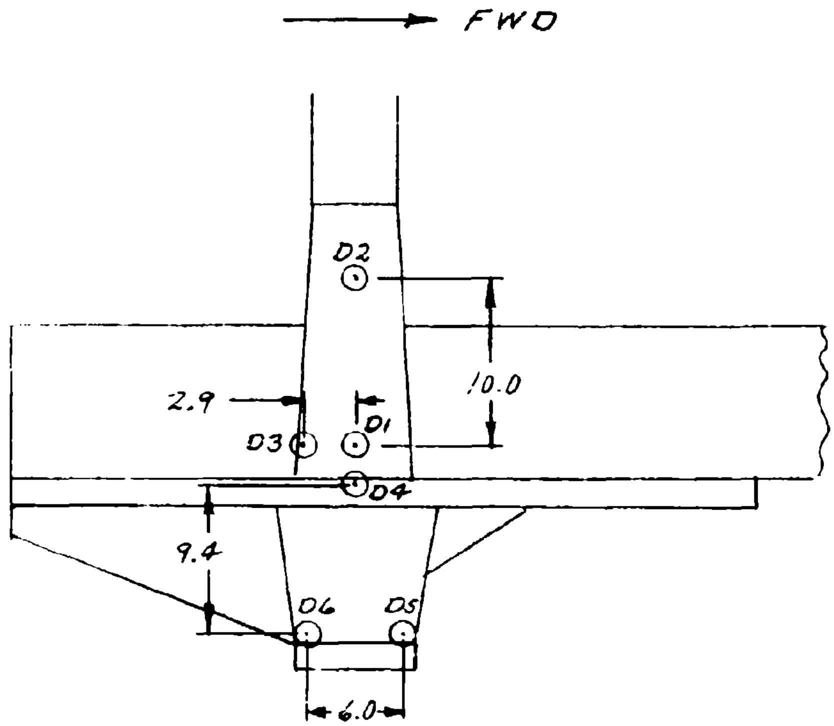


PREPARED BY ZAHAREE
CHECKED BY
APPROVED BY

PAGE 9 OF
DATE 9/5/73
REPORT NO.

TITLE - SUB TITLE

6K ROPS - TEST DATA REDUCTION
VIEW B-B, FAR SIDE (FS)



ZAHAKEE
9/6/73

TEST REPORT ________

LOCKHEED PROPULSION COMPANY
POTRERO DIVERSIFIED TEST FACILITY

ROLL-OVER PROTECTIVE STRUCTURE
TEST DATA SHEET

TEST ITEM 6K-FORKLIFT-ROPS ANALYSIS TEST DATA 8/24/73

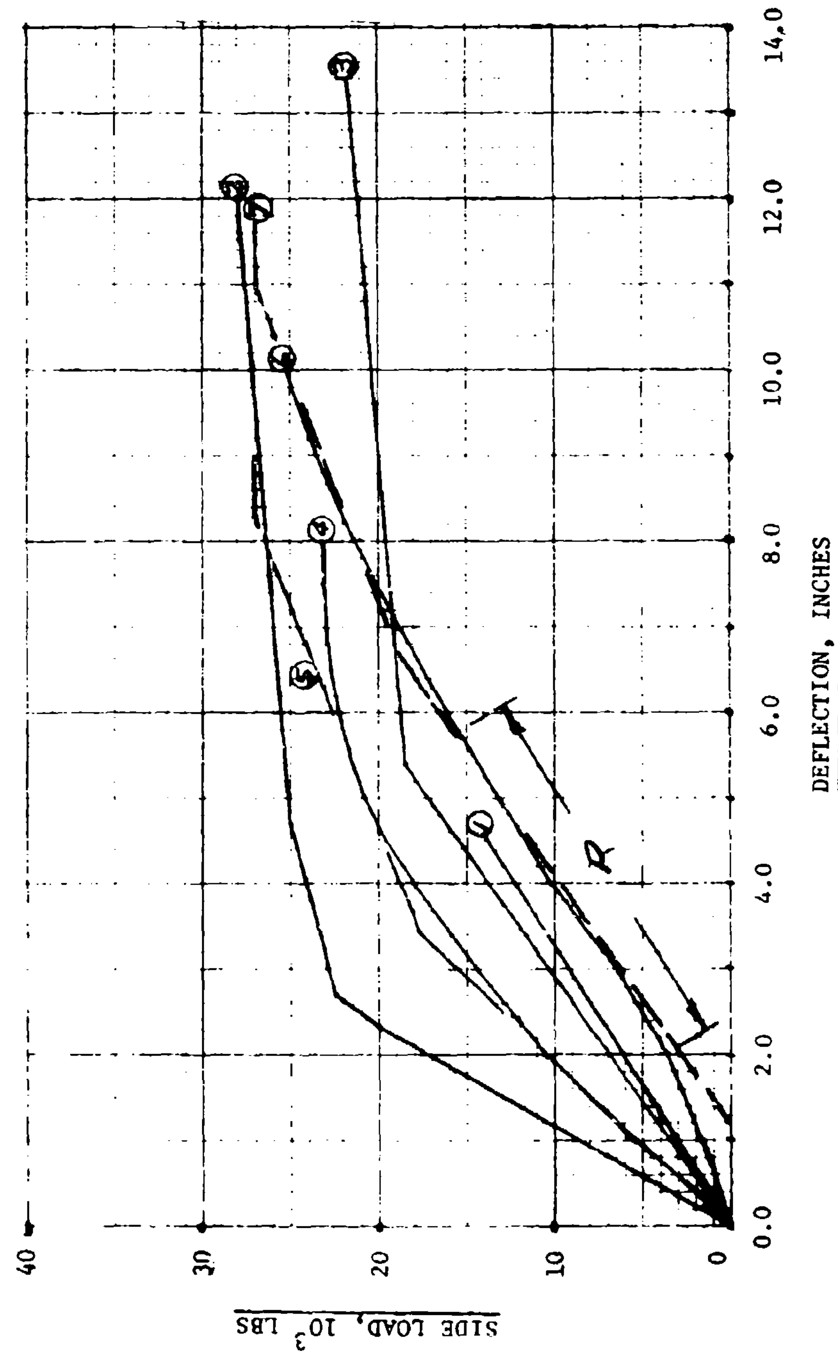
		FS	NS	FS						NS					
DEF	LOAD	ST	ST	D1	D2	D3	D4	D5	D6	D1	D2	D3	D4	D5	D6
ø	ø	619	6	.500	.250	.250	.500	.400	.000	.500	.800	.500	.500	.500	.100
2	03 5112	748	498	.507	.322	.179	.508	.401	.000	.474	.750	.515	.491	.300	.099
4"	11,776	826	365	.517	.491	.150	.520	.392	-.002	.442	.674	.505	.475	.303	.099
6	18,846	865	227	.544	.498	.161	.535	.392	-.003	.420	.590	.489	.465	.310	.182
ø	ø	610	570	.505	.259	.252	.500	.397	.0025	.500	.796	.500	.498	.304	.099
ø	ø			.505	.259	++ .252									
2"	4,798			.504	.337	.186									
4"	11,252			.525	.413 *	.155									
6"	18,911			.552	.513	.166									
ø	ø			.508	.269	.253									
						R									

* .140 MIN VALUE.
++ SMALLER IS OUTBOARD.

Prepared by: ________________ Approved by: ________________

6K ROPS - SIDE LOAD TEST DATA REDUCTION

6K ROPS SIDE LOAD VS. DEFLECTION



See page 1 for explanation of curves

6K ROPS - SIDE LOAD TEST DATA REDUCTION

DEFLECTION, IN.	8/23/73 TEST, REF. PG. 5. 1S	2S	θ_{R1}*	3S	4S	θ_{R2}*	8/29/73 TEST TEST 1 (PG. 8) FS S7	NS S7	θ_{R3}*	NS D1	NS D3	θ_{R4}
0.0	1.00	1.00	0	2.00	2.00	0	6.19	6.00	0	.500	.500	0
2.0	3.45	1.75	.0239	1.25	2.94	.0227	7.48	4.98	.0310	.474	.515	.0070
4.0	6.15	2.50	.0513	0.04	3.30	.0505	8.26	3.69	.0588	.447	.505	.0098
6.0	8.72	2.90	.0816	-1.86	4.09	.0800	8.65	2.77	.0831	.420	.489	.0117

$$*\theta_{R1} = \frac{\Delta\delta}{R} = \frac{\delta_{1S} - \delta_{2S}}{71.25} \text{ RADIANS}$$

$$\theta_{R2} = \frac{\Delta\delta}{R} = \frac{\delta_{3S} - \delta_{4S}}{74.5} \text{ RADIANS}$$

$$\theta_{R3} = \frac{\Delta\delta}{R} = \frac{\delta_{NSS7} - \delta_{FSS7}}{74.5} \text{ RADIANS}$$

$$\theta_{R4} = \frac{\Delta\delta}{R} = \frac{\delta_{NSD1} - \delta_{NSD3}}{5.9} \text{ RADIANS}$$

$$\theta_{R5} = \frac{\Delta\delta}{R} = \frac{\delta_{FSD1} - \delta_{FSD3}}{2.9} \text{ RADIANS}$$

DEFLECTION, IN.	8/29/73 TEST, TEST 1 FS D1	FS D3	θ_{R5}	8/29/73 TEST, TEST 2 FS D1	FS D3	θ_{R5}
0.0	.500	.250	0	.505	.252	0
2.0	.507	.179	.0269	.504	.186	.0224
4.0	.517	.150	.0404	.525	.155	.0404
6.0	.544	.161	.0458	.552	.166	.0959

DEFLECTION IN.	% TORSIONAL FIXITY, NS LEG	% TORSIONAL FIXITY, FS LEG	AVG. % TOR FIXITY, F_T	$K_{TOR}' = K_{TOR} \times F_T$ (PG. 15)	V_E' (PG. 16)	δ_{LONG}' (PG. 15)
0.0	0	0	0	0	.837 P	.000348
2.0	77	13	45	.198	.281 P	.000117 P
4.0	90	51	71	.312	.203 P	.000084 P
6.0	92	78	85	.374	.177 P	.000074 P

$$\%\text{ TORSIONAL FIXITY, NS LEG} = \frac{\theta_{R3} - \theta_{R4}}{\theta_{R3}}$$

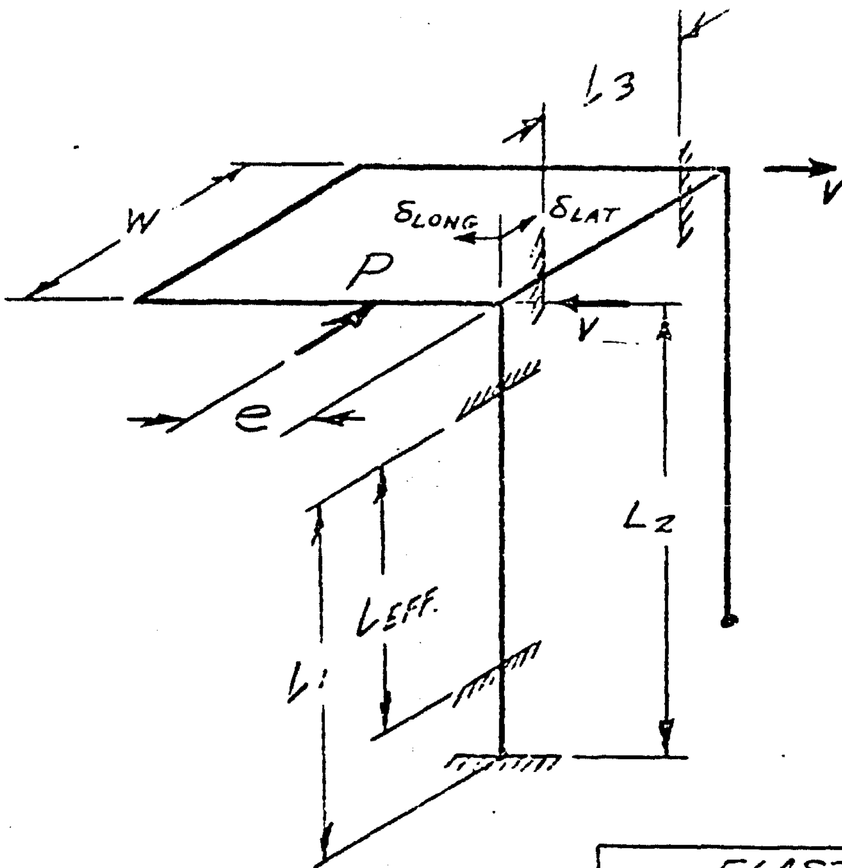
$$\%\text{ TORSIONAL FIXITY, FS LEG} = \frac{\theta_{R3} - \theta_{R5}}{\theta_{R3}}$$

$$V_E' = \frac{K_{BE}}{K_{BE} + K_{TOR}'}\left(\frac{Pe}{W}\right) \qquad \delta_{LONG}' = \frac{V_E' L_2^3}{3EI} \text{ (PG. 15)}$$

$$\Sigma\delta' = \delta_{LAT} + \delta_{LAT} + \frac{e}{2}(\delta' \ ) \qquad m = \frac{F}{\delta'}$$

DEFLECTION IN.	$\Sigma\delta'$	m, SLOPE #/IN
0.0	.000763 P	1310
2.0	.000376 P	2660
4.0	.000319 P	3140
6.0	.00030[illegible] P	[illegible]

ROPS LOAD VS. DEFLECTION CALCULATION



L_{EFF} = LENGTH FROM POST FOOT TANGENT TO 1" INTO UPPER GUSSET.

L_1 = DISTANCE FROM TOP OF SOCKET TO 5" INTO UPPER GUSSETT.

L_2 = DISTANCE FROM TOP OF SOCKET TO UPPER STRUCTURE ℄.

L_3 = LENGTH 5" INTO GUSSET ON EACH SIDE.

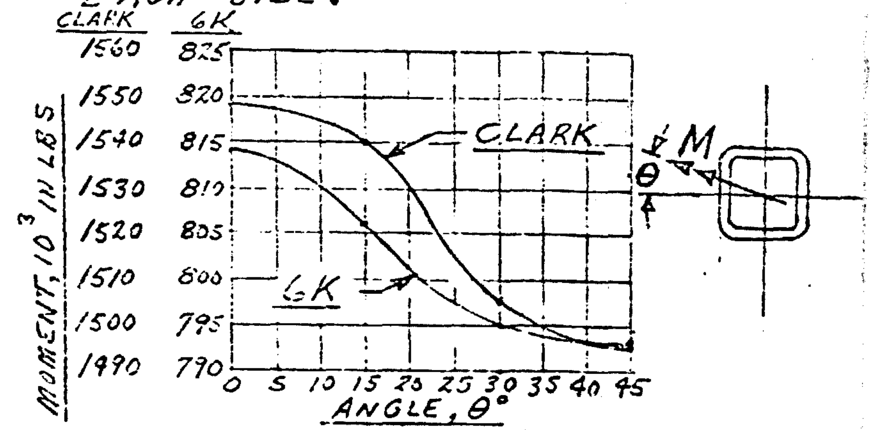


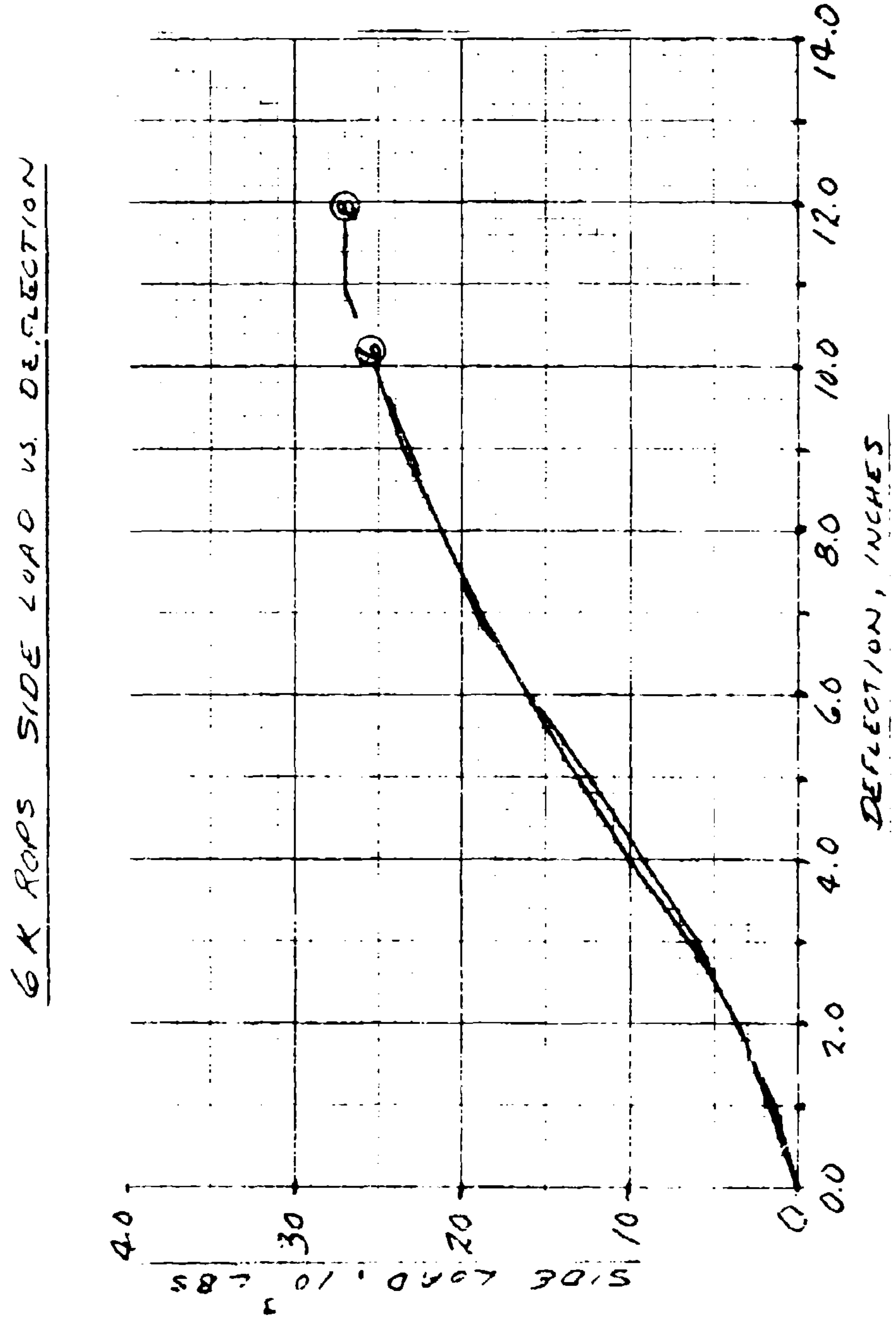
FIG. I ULT. BEND MOMENT CAPABILITY VS. MOMENT ANGLE.
F_{TU} = 77,400 PSI

										10^6 IN LB/IN				ELASTIC CURVE				ULTIMATE CAPABILITY					
														$\frac{PL_1^3}{6EI}$	$L_2 \frac{P}{\frac{W}{2}} \frac{(\frac{L_3}{2})^3}{3EI}$	$\frac{V_E L_2^3}{3EI}$	$\delta_{LAT_1} + \delta_{LAT_2} + \frac{e}{\frac{W}{2}} \cdot (\delta_{LONG})$		$\frac{P}{2} \cdot \frac{L_{EFF}}{2}$	$V_U \cdot \frac{L_{EFF}}{2}$	$M_{LAT} \leftrightarrow M_{LONG}$		$\frac{M_{FIG.1}}{COEF. P}$
VEHICLE	SIZE	I	J	L_{EFF}	L_1	L_2	L_3	W	e	K_{TOR}	K_{BE}	K_{BU}	V_E	δ_{LAT_1}	δ_{LAT_2}	δ_{LONG}	$\Sigma\ \delta$, IN.	V_U	M_{LAT}	M_{LONG}	M	θ	P, LB.
CLARK	$6 \times 6 \times \frac{1}{2}$	18.3	83.9	56.5	49	61	46	72	14.3	.83	1.33	.25	.122 P	.0000140 P	.0000042 P	.0000066 P	.0000208 P	.176 P	9.12 P	3.21 P	9.70 P	19°	158,000
GK	$5 \times 5 \times \frac{3}{8}$	21.9	40.2	75.5	55	72.5	27	43	36	.44	.10	.76	.155 P	.000161 P	.000019 P	.000064 P	.00029 P	.530 P	18.90 P	20.06 P	27.5 P	43°	28,900

$$K_{TOR} = \frac{1}{\delta} = \frac{1\ IN\ LB}{R\frac{TL}{JG}} = \frac{1\ IN\ LB}{\frac{W}{2} \cdot \frac{1}{2} \cdot \frac{L_2}{JG}} \qquad K_{B_E} = \frac{1}{\delta} = \frac{1\ IN\ LB}{\frac{1}{W} \cdot \frac{L_2^3}{3EI}} \qquad K_{B_U} = \frac{1}{\delta} = \frac{1\ IN\ LB}{\frac{1}{W} \cdot \frac{L_{EFF}^3}{12EI}}$$

$$V_E = \frac{K_{BE}}{K_{BE} + K_{TOR}} \left(\frac{Pe}{W}\right) \qquad V_U = \frac{K_{BU}}{K_{BU} + K_{TOR}} \left(\frac{Pe}{W}\right) \qquad P_S = \frac{P}{2} \cdot \frac{L_2}{\frac{W}{2}}$$

6K ROPS - SIDE LOAD TEST DATA REDUCTION



APPENDIX 6.8

INSTALLATION INSTRUCTIONS

Service Bulletin 112

Retrofit Procedure for Installation of Roll-Over Protective Structure (ROPS)

on

6000 lb Forklift Truck

Installation Drawing 299279

NOTE: All Welding to be per DPSF100.

A. PARTS REQUIRED

Item	Drawing No.	Quantity	Description
1.	299024-501	1	Roll-Over Protective Structure
2.	299239-501	1	Attachment Structure Assembly
3.	299239-509	1	Attachment Structure Subassembly
4.	299239-135	1	Spacer plate, R.H.
5.	299239-137	6	Back-up plate
6.	299239-139	2	Back-up plate
7.	299239-141	1	Spacer plate, L.H.
8.	299572-103	2	Flat washer, 4.0 dia.
9.	299572-107	1	Spacer block
10.	299572-109	2	Bevel nut
11.	299029-101	4	Resilient pad (Fabreeka)
12.	299029-103	4	Resilient pad (Fabreeka)
13.	299029-105	2	Resilient washer (Fabreeka)
14.		2	Cap SCR, H.H. self-locking 1.25-7 UNC, 4.5 long
15.		28	Bolt, H.H. SAE grade 8 3/4-10 UNC, 4.0 long
16.		28	Hex nut, SAE grade 8 3/4-10 UNC
17.		28	Flat washer, 3/4 medium
18.		28	Lock washer, 3/4 medium
19.		2	Bolt, H.H. SAE grade 8 1/2-13 UNC, 1-1/4 long
20.		2	Flat washer, 1/2 medium

A. PARTS REQUIRED (Continued)

Item	Drawing No.	Quantity	Description
21.		2	Lock washer, 1/2 medium
22.		2	Hex nut, SAE grade 8 1-1/4-7 UNC
23.		2	Mach Scr. H.H. 3/8-16 UNC, 3/4 long
24.		2	Flat washer, 3/8
25.		2	Lock washer, 3/8
26.		1	Hose adapter fitting, MS20822-12
27.		1	Electric Harness, single conductor. Cable, MIL-C-13486-1, Type I, Class A with female connector, MS27144-1 Style 1 at one end and male connector, MS27142-2 at other end. Total length 56 inches.
28.		1	Electric harness, similar to Item 27 except 140 inches long.
29.		11	Wire clamps, MS21105-3
30.		11	Self-tapping screw, No. 10 pan head, 3/4 long
31.		4	10/24 Mach Scr. R.H. 3/4 long
32.		15	No. 10 flat washer
33.		15	No. 10 lock washer
34.		As Required	Molykote lubricant
35.		As Required	Adhesive, rubber-to-metal AMICON 2654

B. PREPARATION OF LIFT TRUCK FOR RETROFIT

NOTE: Retain all fasteners for use in re-assembly.

1. Place truck on level hard surface.
2. Securely block up rear axle and remove rear wheels by unscrewing 10 stud nuts on each wheel. Set aside the two wheels, and run nuts partly on studs to protect the threads during the retrofit.
3. Disconnect the short electrical harness serving the floodlight on the forward edge of the overhead guard.
4. Remove the 4 clevis pins and lift off the overhead guard.
5. Torch cut the floodlight bracket from the guard for later welding to the ROPS.
6. Unlatch and lift off the left hand and right hand engine covers and unscrew the two forward latches from the frame.
7. Disconnect from the air cleaner outlet the tube coming from the air cleaner service indicator. See Figure 1
8. Remove the two screws attaching the service indicator to its mounting lug on the hydraulic reservoir.
9. Pull the service indicator and its tube out of the mounting lug, reverse its direction and thread back into the lug, so that the indicator unit is on the inward side toward the truck centerline.
10. Replace the two attaching screws and tighten hand tight.
11. Unfasten the clamp from the flexible air duct on the outlet of the air cleaner.
12. Remove the four bolts holding the air cleaner to the left hand rear fender, and the one bolt attaching the air cleaner stack brace to the fender.
13. Lift off the air cleaner with its stack and brace and set aside.
14. Remove the 12 bolts attaching the hood to the chassis.
15. Loosen the clamp under the hood attaching the muffler to the exhaust stack.
16. Remove the 8 bolts attaching the left hand rear fender to the chassis.
17. Remove the 10 similar bolts from the right hand rear fender.
18. Raise the loosened hood and muffler to clear the 3/4" lip on the left hand rear fender and remove the fender.

B. PREPARATION OF LIFT TRUCK FOR RETROFIT (Continued)

19. Similarly, remove the right hand rear fender.

20. Remove the 8 bolts attaching the left hand panel cover forward of the latched cover and remove the panel.

21. Remove the 11 bolts attaching the right hand panel cover forward of the latched cover and remove the panel.

22. Remove the 10 bolts attaching the bent panel forming the forward wall of the left hand wheel well and remove the panel.

23. Cut a 2" notch in the skirt of the right hand wheel well panel as shown in Figure 2.

24. Remove 2-1/2 inch bolts, nuts and washers from angle structure (one on each side of chassis) and replace with 1/2 inch bolt 1-1/4 long, flat washer, lock washer, and bevel nut Item 10 as shown in Figure 2.

25. Remove 4-3/4" bolts attaching the counterweight to the frame and remove the weight. Take care to avoid damage to the electric wires in the area.

26. Clean the truck frame and chassis exposed by these removals with steam or solvent to permit suitable working conditions.

27. Torch-cut the 2 aft tie-down lugs from the outside face of the frame. That portion of the lug root above the 1" thick axle mount support plate must be ground down flush or below the edge of the plate. That portion of the lug root under the reinforcement must be ground down to 1/4" below this flush level. (Do not grind away any part of the plate or the frame channel.) See Figure 1

28. On the right hand side of the engine, re-locate the two oil cooler hoses: Figure 3 shows the existing connections. Step a) Remove the bolt holding the two hose clips to the hose clip support angle. b) Disconnect and remove the 45° adapter fitting from the forward connection in the oil cooler, catching the small amount of oil in a receptacle. c) Install the 90° fitting included in the retro-fit kit (Item 26). d) Re-connect the forward hose. e) Attach the spacer block (Item 9) in the hose clip support angle with 3/8 inch screw, washer, and lock washer (Items 23, 24, 25), screwed up into the threaded hole in the spacer block.
f) Remove the hose clips from the two hoses, turn them over, and replace them on the hoses so that they can be attached on the top side of the spacer block. g) Attach the two clips to the top of the spacer block with one 3/8 inch screw, washer, and lock washer (Items 23, 24, 25); screwed into the threaded hole in the spacer block. See Figure 4

C. INSTALLATION OF ATTACHMENT STRUCTURE

1. Locate Spacer Plate 299239-141 (Item 7) on left hand side of the chassis frame channel as shown on Figure 5 and tack weld as shown.

2. Similarly, locate Spacer Plate 299239-135 (Item 4) the right-hand side and tack weld. See Figure 5.

3. From directly behind the truck, move the Attachment Structure Assembly 299239-501 (Item 2) forward under the chassis, with the longer extension on the right hand side. A fork lift truck is suggested for this operation. The longer extension must be raised at the forward end to pass over the axle during the move. See Figure 6.

4. Raise the assembly up underneath the chassis so that the top of the right hand extension is level with the top of the chassis frame channel. Move the assembly forward so that its cross beam contacts the aft face of the 1" thick axle mount support plate shown in Figure 7. (The top of the ROPS socket will be 1/8" below the bottom of the frame channel.)

5. Clamp the right hand extension of Assy 299239-501 to the right hand channel frame, with the tack welded spacer plate in between. (Figure 8)

6. Level the assembly by jacking or blocking the left hand end of the cross beam.

7. Check level and location of the sub-assembly as follows:

   a. Right hand extension level, flush with the top of the right hand frame channel, and clamped snugly against the channel and spacer plate (Item 4).

   b. Forward face of cross beam in contact with the aft end of the axle mount support plate on both sides of the chassis frame. Top of ROPS socket 1/8" below bottom of the frame channel, both sides.

8. Securely clamp the Attachment Structure to the right hand frame channel and, using the fourteen 3/4" diameter holes as guides, drill through spacer plates and frame channel with a 3/4" drill in fourteen places. (Figure 9)

9. The fourteen 3/4" diameter holes are arranged in three patterns of 4 holes each and one group of 2 holes. Back-up plate 299239-137 (Item 5) is used for each of the 4-hole patterns and back-up plate 299239-139 (Item 6) is used for the 2-hole pattern.

C. INSTALLATION OF ATTACHMENT STRUCTURE (Continued)

10. Place a 4-hole back-up plate, (Item 5) inside the frame channel behind the aft 4-hole pattern. Lubricate the shanks, threads and underside of the heads of four 3/4-10 UNC bolts, with molykote, insert through side-plate, spacer, channel, and back-up plate, add flat washers and lock washers, and screw on the 3/4-10 UNC hex nuts, hand tight.

11. Similarly, using two more back-up plates Item 5 and one Item 6, insert and hand tighten 10 more lubricated bolts, washers, lock washers and nuts.

12. With a wrench holding the nuts on the inside of the frame channel, tighten the fourteen bolts to 125 foot-lbs of torque.

13. Securely clamp the left hand subassembly, 299239-509 to the left hand frame channel in the position shown in Figure 10.

14. Weld the -509 subassembly to the -501 assembly along the left hand side as shown on Figure 10. The welding consists of one 1-inch chamfer weld 8-5/8 inches long, continuous with one 3/4-inch chamfer weld 23-1/4 inches long, one 2-inch chamfer weld 3-1/2 inches long, and two 3/8-inch fillet welds 3-1/2 inches long. The welding procedure must prevent distortion or relative movement between the parts being joined.

15. Drill fourteen 3/4" diameter holes similarly to paragraph 8 above. Exercise care to avoid damage to tubing and electrical lines inside the frame channel, particularly at the forward end of the attachment structure.

16. Place four back-up plates in their appropriate positions inside the left hand frame channel, and install the fourteen lubricated bolts, washers, lock washers and nuts. Tighten the bolts to 125 foot-lb of torque.

D. REWORK OF FORKLIFT TRUCK COMPONENTS

1. Floodlight bracket: Trim the bracket to fit the 2-1/2" diameter beam at the front of the ROPS and weld in place per Figure 11.

2. Left hand latched engine cover: Cut in two pieces, relocate the two hooks and rework the bottom edges as shown in Figure 12.

3. Right hand latched engine cover: Rework similarly as shown in Figure 12.

4. Left hand rear fender: Cut rectangular opening and drill three holes per Figure 13.

D. REWORK OF FORKLIFT TRUCK COMPONENTS (Continued)

5. Right hand rear fender: Cut square opening per Figure 14.

6. Left hand panel cover forward of the latched cover: Cut off the downward projection and bend up the lower edge as shown in Figure 15.

7. Right hand cover panel forward of the latched cover: Cut off the corner and bend up the lower edge as shown in Figure 16.

8. Bent panel forming front wall of left hand wheel well: No rework of this part is required.

E. INSTALLATION OF ROLL-OVER PROTECTIVE STRUCTURE

1. Install the re-worked left hand rear fender. Only 7 bolts are required, because one bolt hole has been cut out in the rework.

2. Install the reworked right hand rear fender using the 10 bolts required.

3. Lower the muffler, and the hood to fit over the 3/4 inch lips on the two fenders.

4. Re-tighten the clamp attaching the muffler to the exhaust stack.

5. Re-attach the hood, using the 12 bolts required.

6. Hoist the ROPS by means of a sling attached to the two lifting lugs and lower it so that the two feet pass through the openings in the rear fenders and hang just above the two sockets in the attachment structure. The feet should be centered on the sockets; adjust the center distance by means of the tie rod if necessary.

7. Install two tapered resilient pads (Item 11) on the inner vertical faces of each socket, using the rubber-to-metal adhesive (Item 35). Then install two rectangular resilient pads (Item 12) on the inner sloping faces. The pads must be bottomed in the socket, and will extend almost 2 inches above the top. Be sure to follow the above sequence: tapered pads first.

8. Before the adhesive cures, carefully lower the ROPS making sure the resilient pads are not displaced. One man at each socket is recommended. The ROPS will bottom against the sloping pads. See Figure 17.

9. Place one large flat washer (Item 8) on one self-locking cap screw (Item 14), then add one resilient washer (Item 13), insert through the hole in the underside of one socket into the threaded hole in the bottom of the ROPS foot, and hand tighten. Follow this same procedure for the other leg of the ROPS. Tighten both cap screws to a torque of 300 foot-pounds.

E. INSTALLATION OF ROLL-OVER PROTECTIVE STRUCTURE (Continued)

10. Loosen the four nuts on the ROPS tie-rod to remove any strain on the rod, then re-tighten to eliminate any looseness.

F. REPLACEMENT OF FORK LIFT TRUCK COMPONENTS

1. Replace the bent panel forming the forward wall of the left hand wheel well, using 10 bolts.
2. Replace the left hand panel cover forward of the latched covers, using 4 machine screws.
3. Replace the right hand panel cover forward of the latched covers, using 8 machine screws.
4. Attach one cover latch to the left hand side of the attachment structure with two 10/24 machine screws threaded into the tapped holes, forward of the ROPS post.
5. Attach one cover latch to the right hand side of the attachment structure in the same way.
6. On the left hand side, pass engine cover "A" behind the ROPS post from the rear, hook in place and secure with the latch.
7. On the right hand side, install the "C" engine cover in the same way.
8. On the left hand side, install the engine cover "B".
9. On the right hand side, install the engine cover "D".
10. Install the air cleaner, attaching to the left hand rear fender by means of 3 bolts through the three new holes and one bolt through the original slotted hole.
11. Re-connect the flexible air duct to the air cleaner outlet, and tighten the clamp.
12. Re-connect the service indicator tube to its boss on the air cleaner outlet.
13. Loosen the clamp attaching the brace to the air cleaner inlet stack.
14. Slide the loosened clamp upward to permit the lower end of the brace to match its original bolt hole in the fender.
15. Bolt the lower end of the brace to the fender with one bolt.
16. Plumb the air cleaner inlet stack and re-tighten the clamp.

F. REPLACEMENT OF FORK LIFT TRUCK COMPONENTS (Continued)

17. Attach electric harness Item 27 (56 inches long) on the chassis as shown in Figure 18, extending from front of cockpit to top of left hand rear fender adjacent to ROPS post.

18. Attach electric harness Item 28 (140 inches long) to ROPS post and upper horizontal beam to serve flood light mounted on forward round beam (Figure 18).

19. Re-install the counterweight.

20. Mount the two rear wheels back on the truck.

21. Remove all blocking.

10342

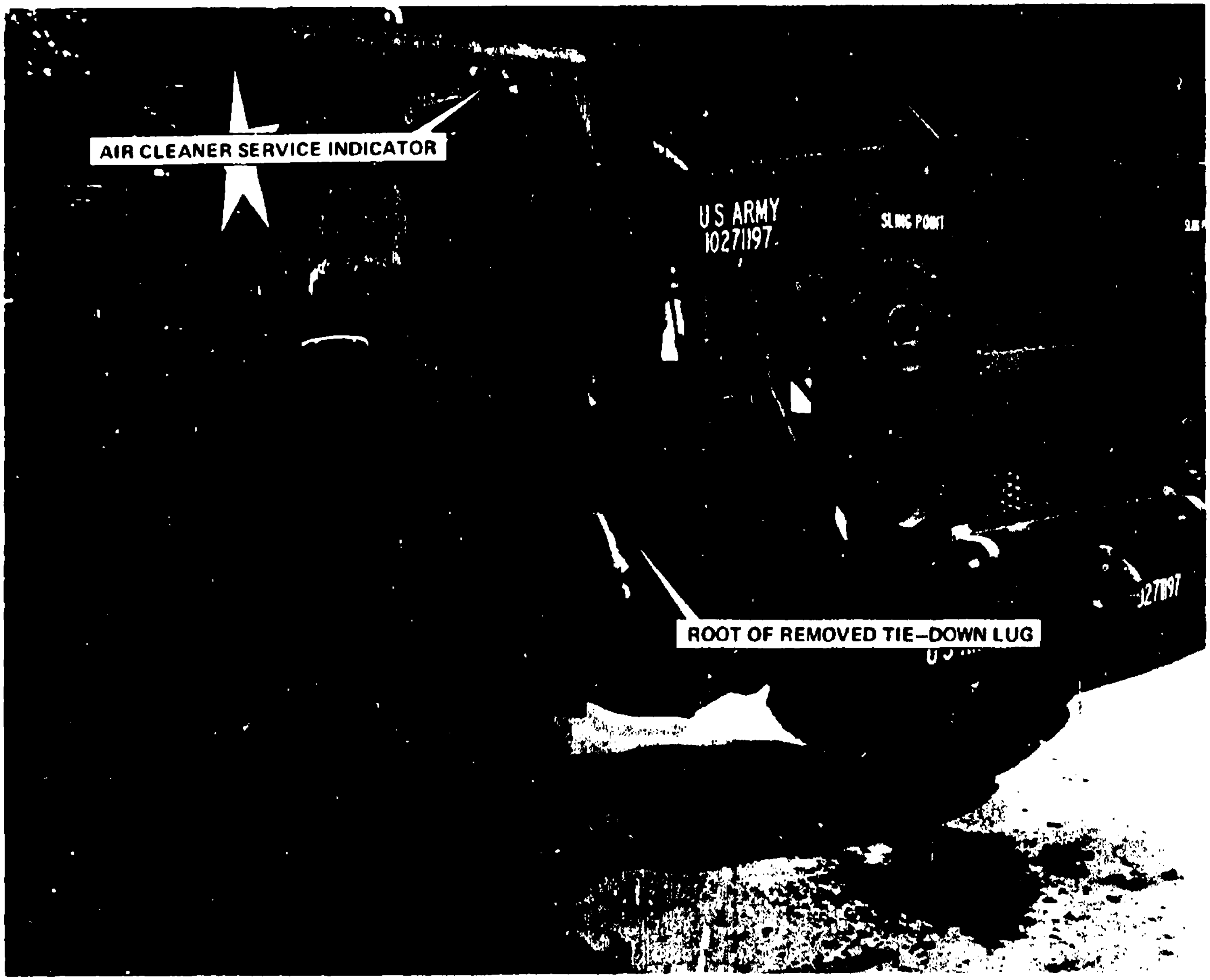
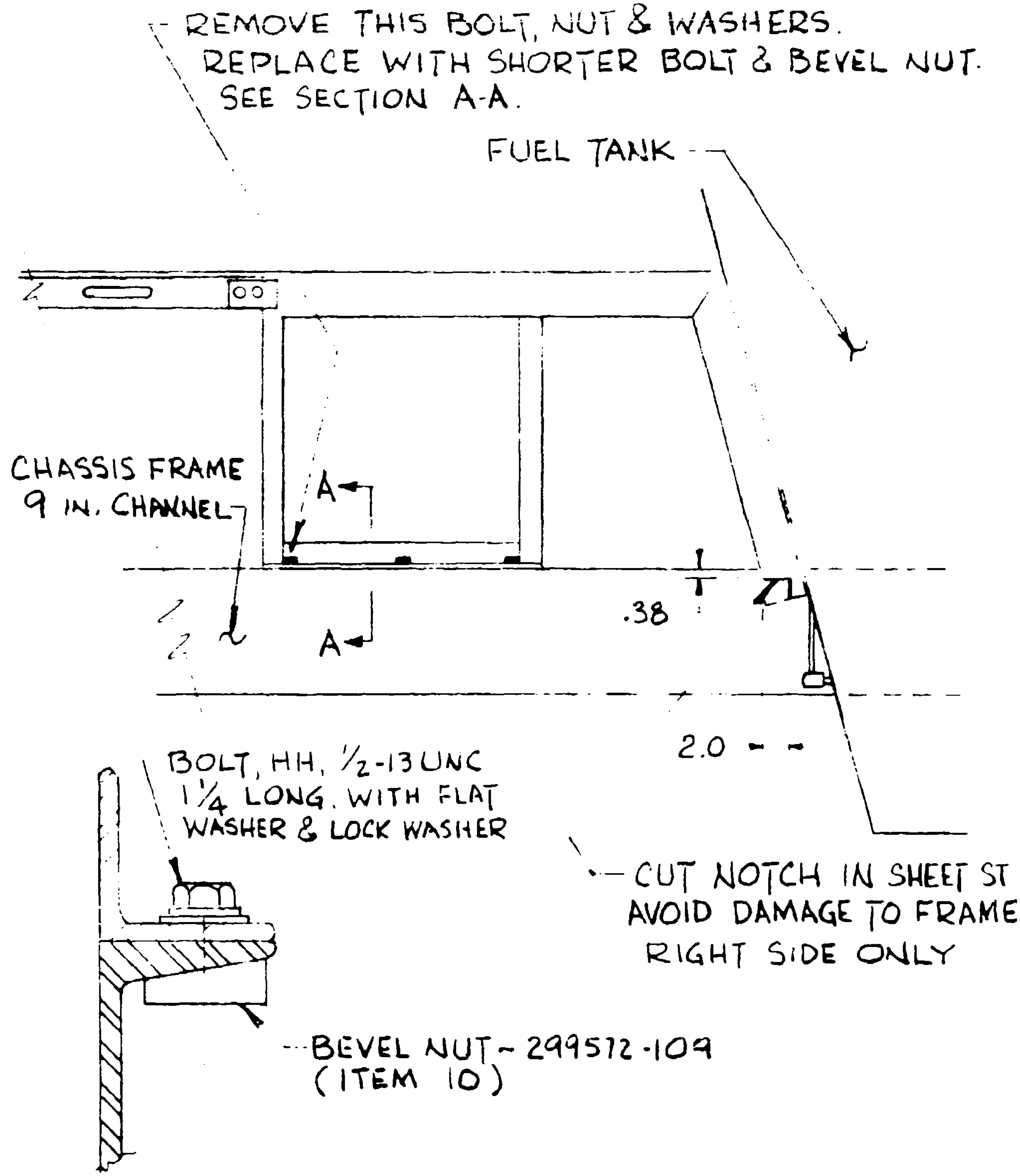


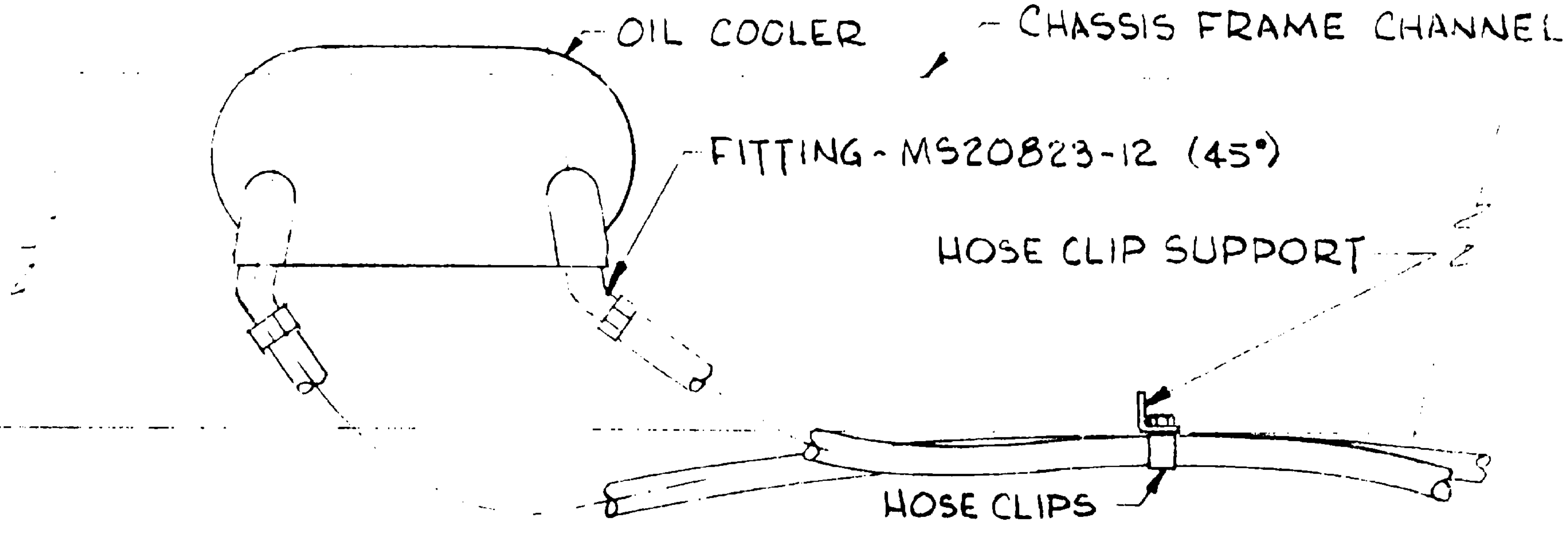
Figure 1. Left-Hand Side, Showing Air Cleaner Service Indicator and Tiedown Lug Root



SECTION A-A
TYP 2 SIDES
OF FRAME

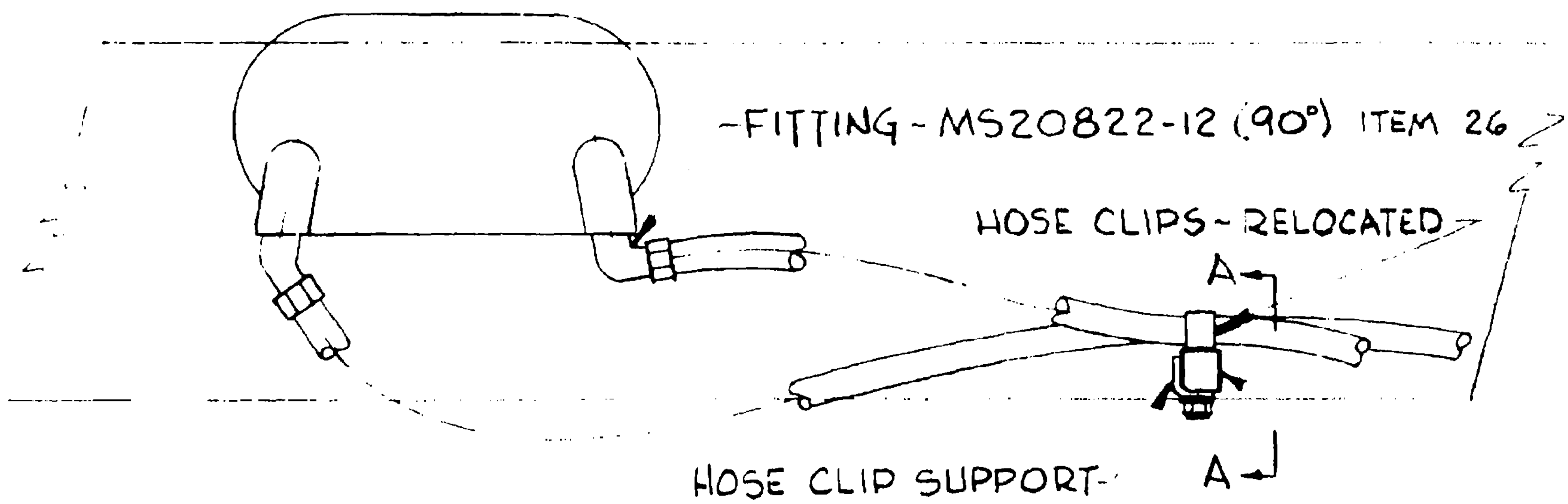
CHASSIS REWORK
RIGHT SIDE SHOWN

FIGURE 2

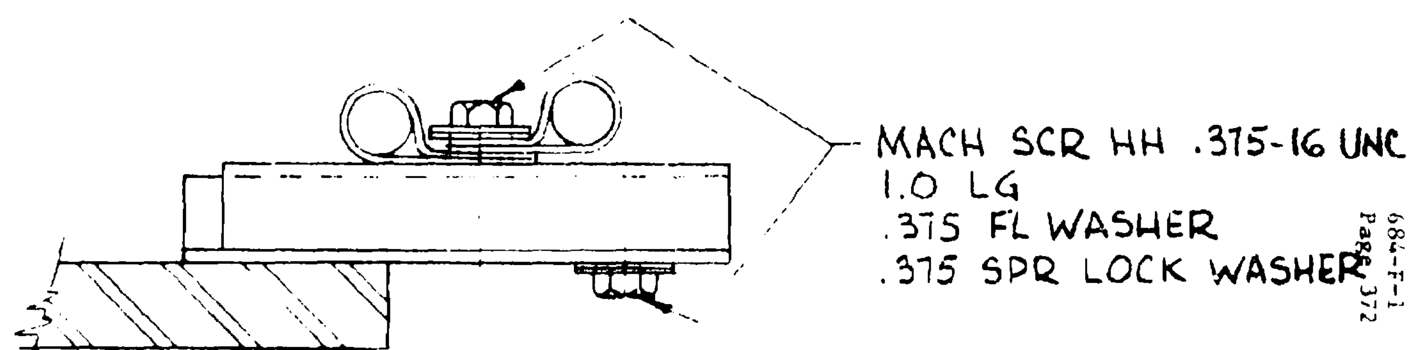


EXISTING OIL COOLER CONNECTIONS
SEEN FROM RIGHT HAND SIDE

FIGURE 3

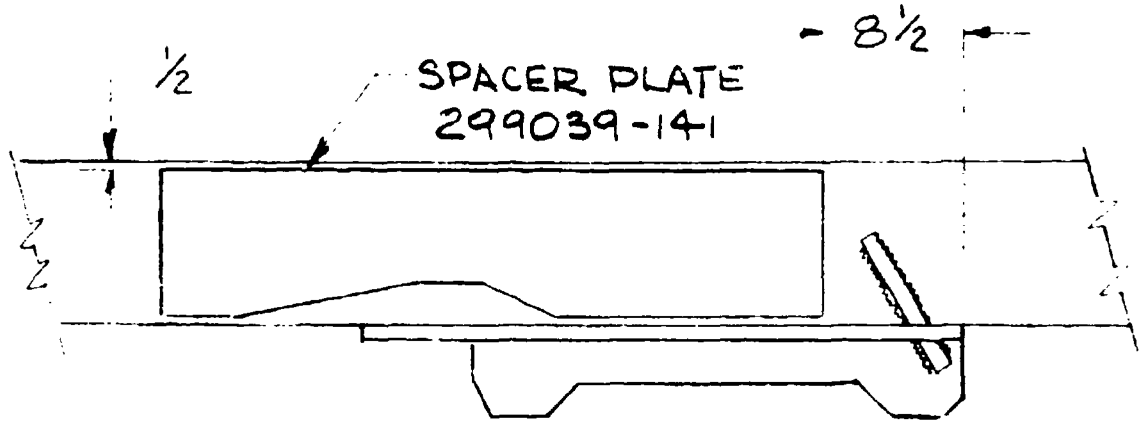


REWORKED OIL COOLER CONNECTIONS

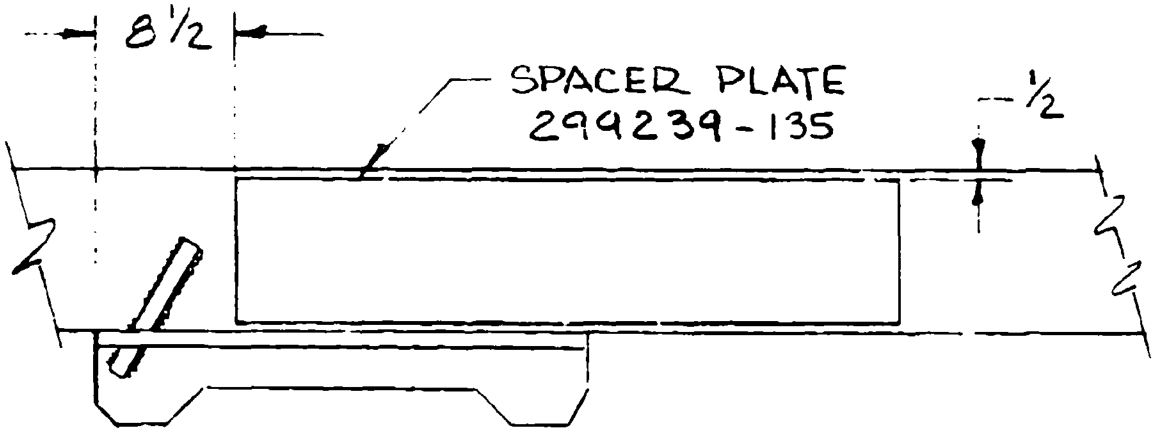


VIEW A-A

FIGURE 4



LEFT HAND SIDE VIEW



RIGHT HAND SIDE VIEW

SPACER PLATE LOCATIONS

FIGURE 5

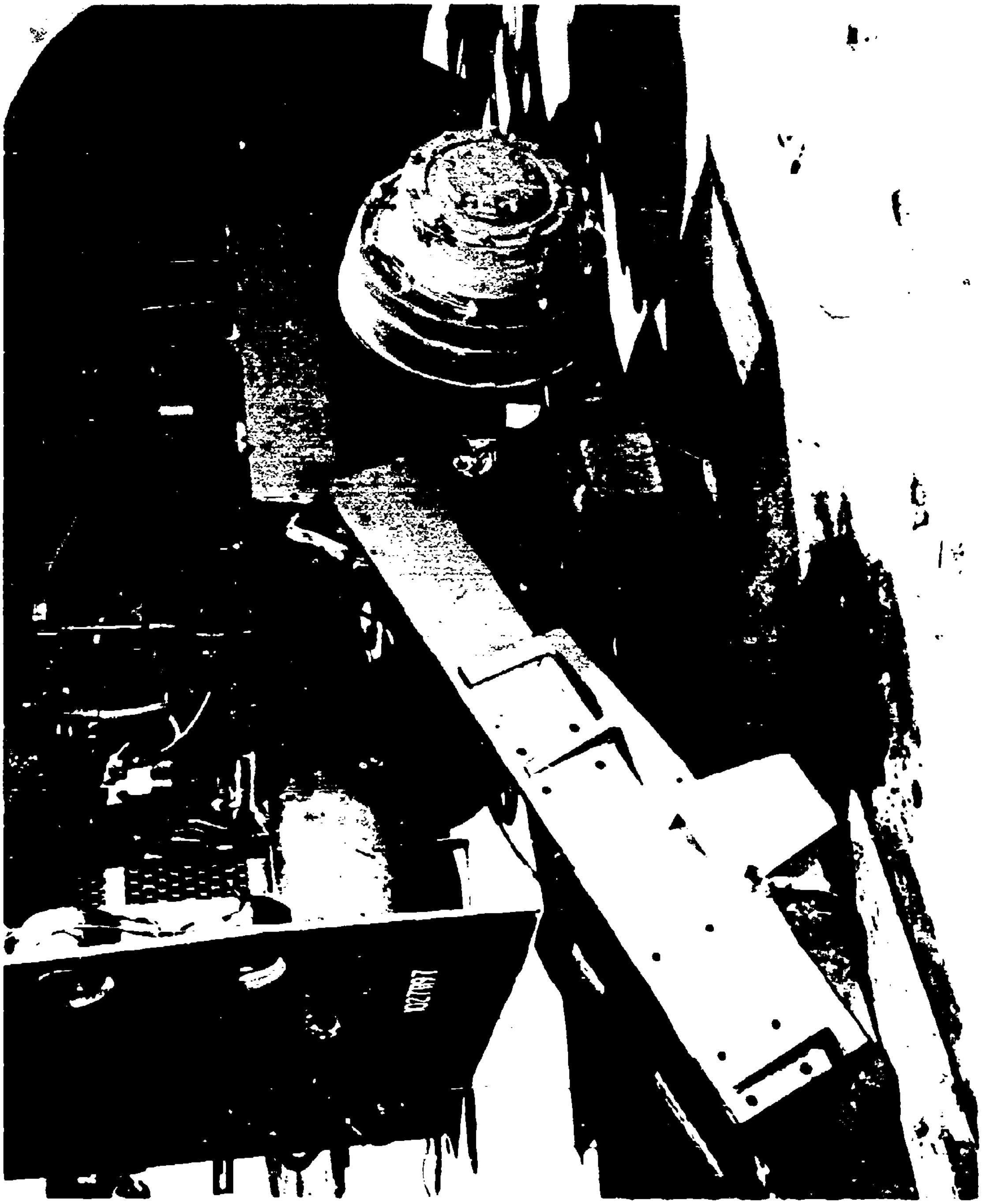
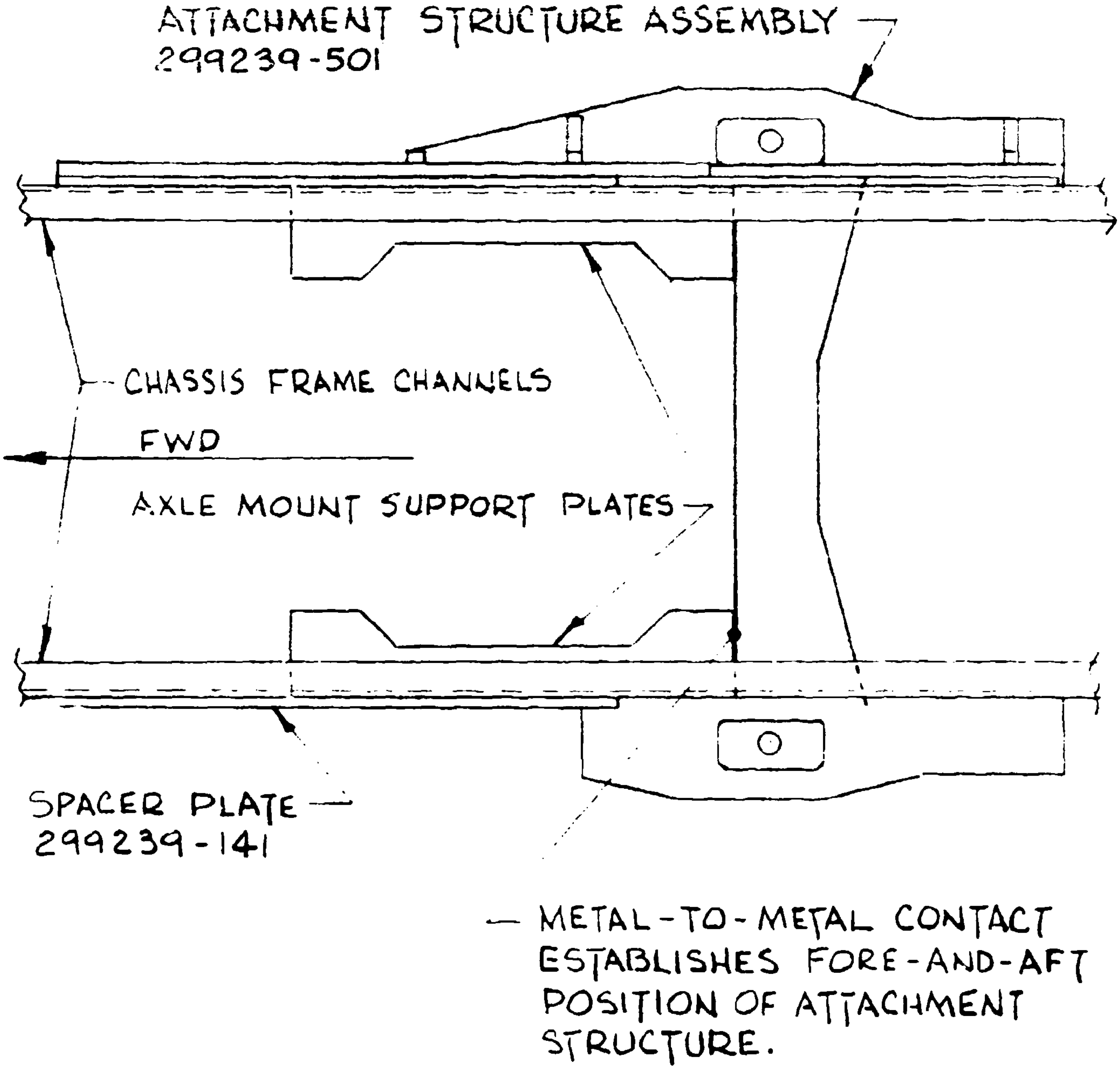


Figure 6. Attachment Structure Being Placed

10445



LONGITUDINAL POSITION OF ATTACHMENT STRUCTURE

FIGURE 7

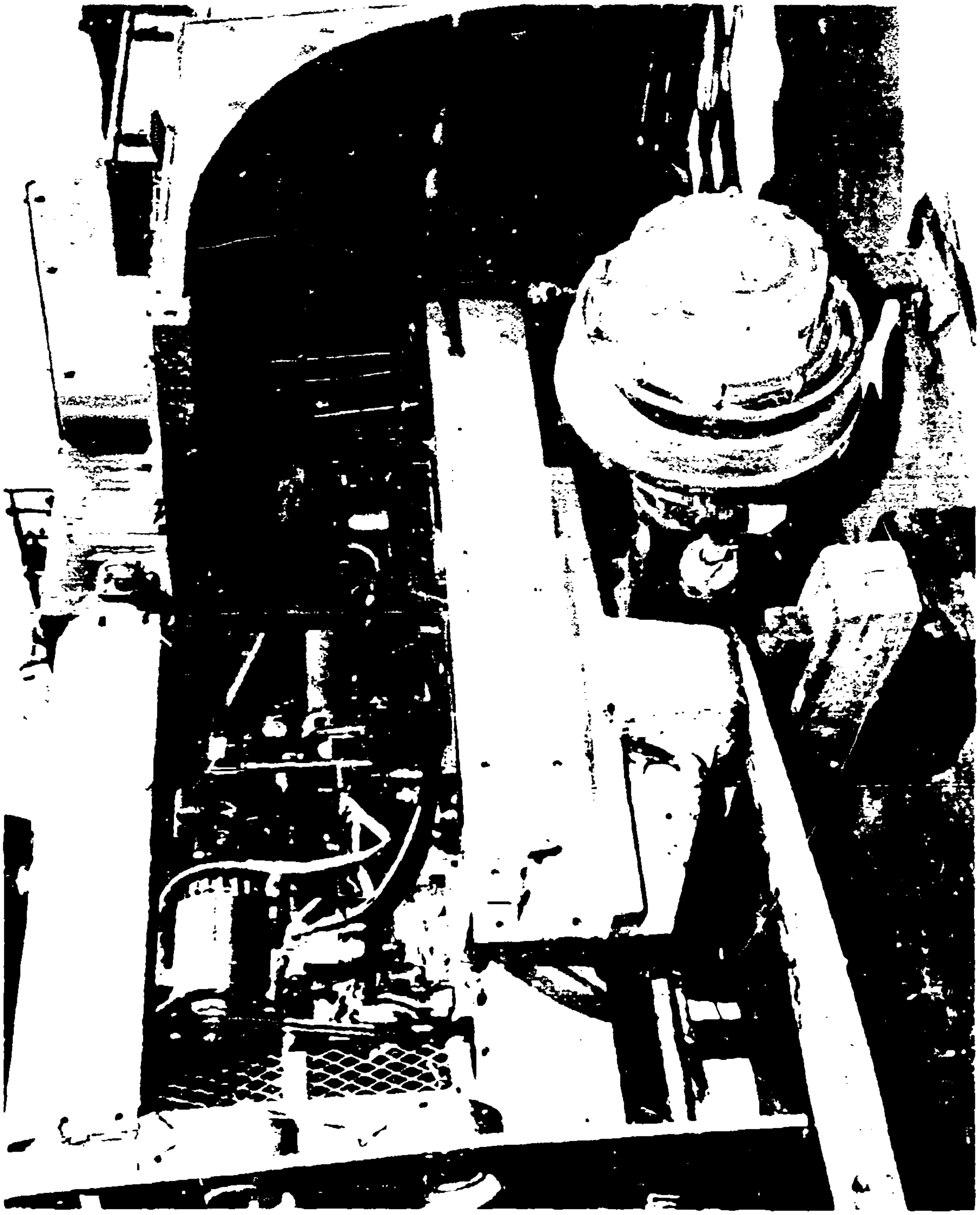


Figure 8. Attachment Structure Clamped in Place

1033

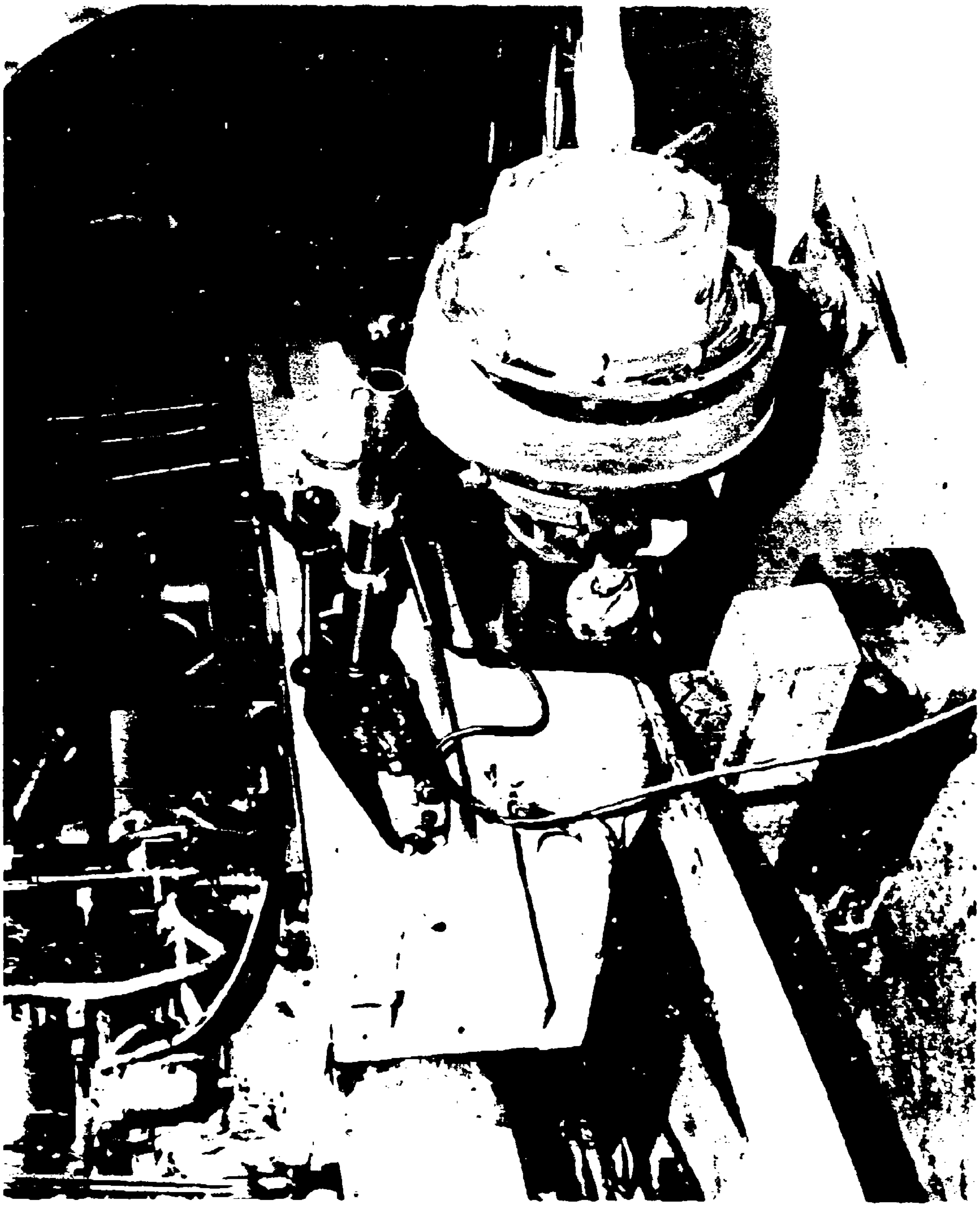


Figure 9. Drilling Rig in Place

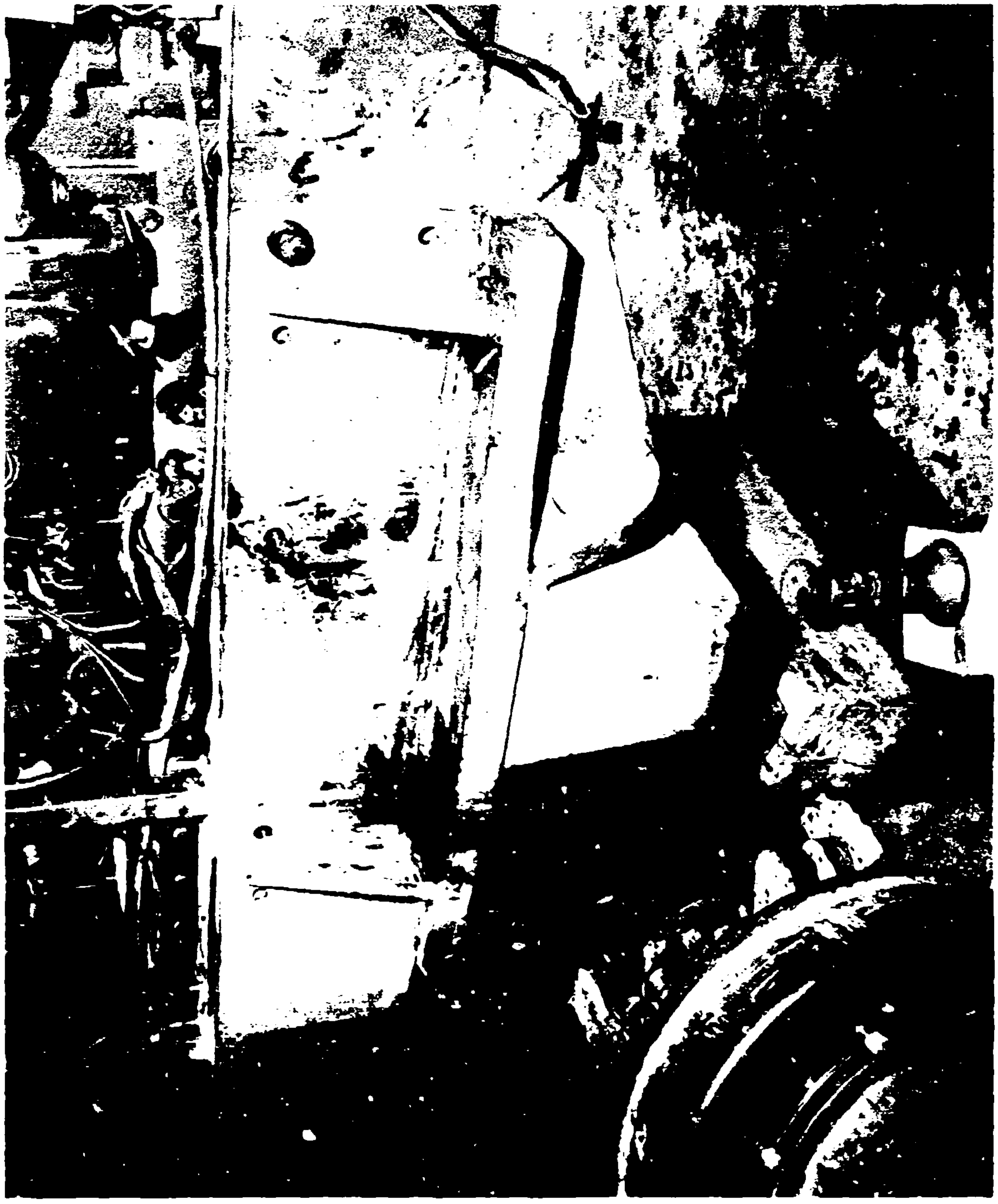


Figure 10. Left-Hand Subassembly Welded in Place

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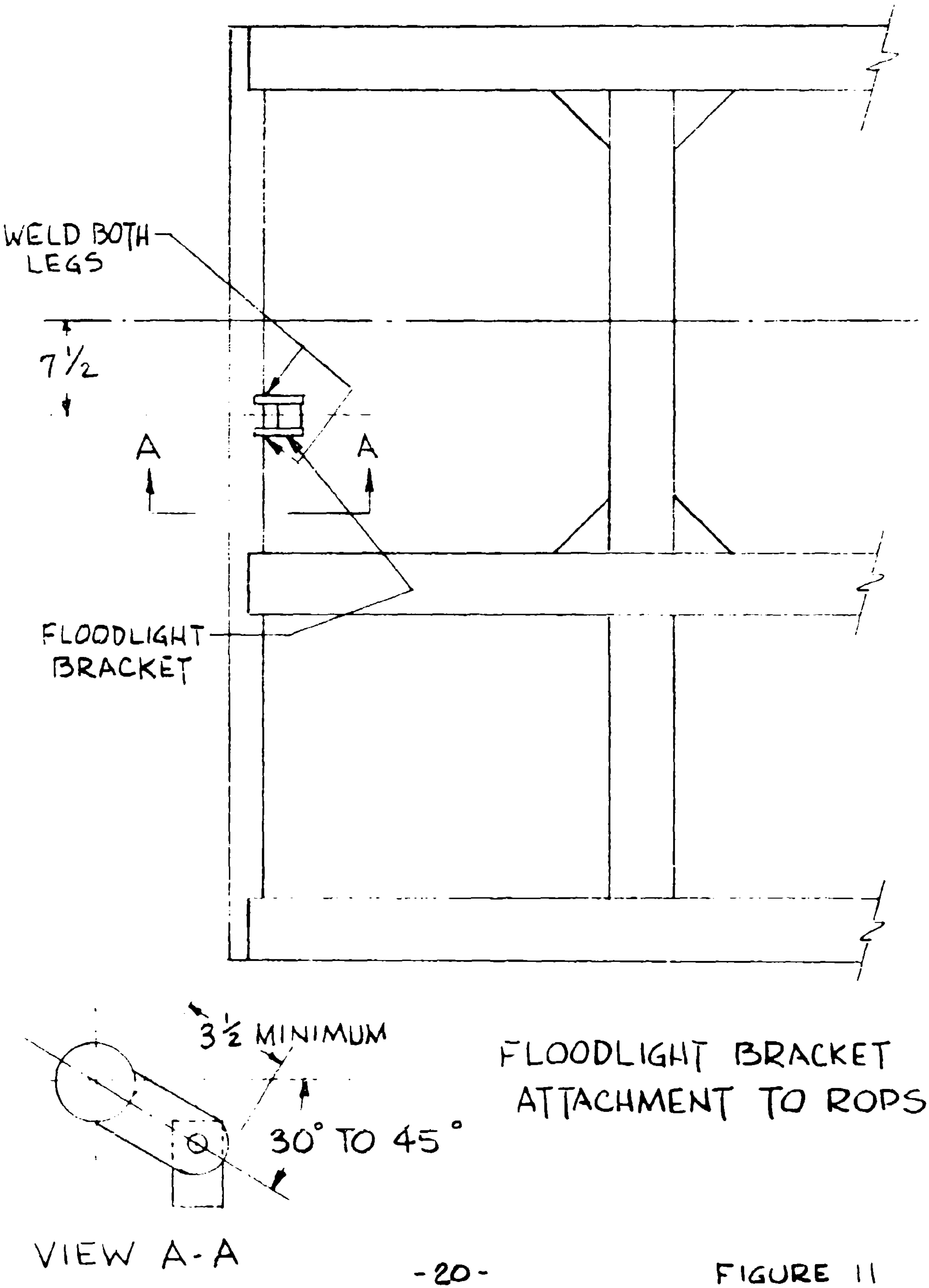
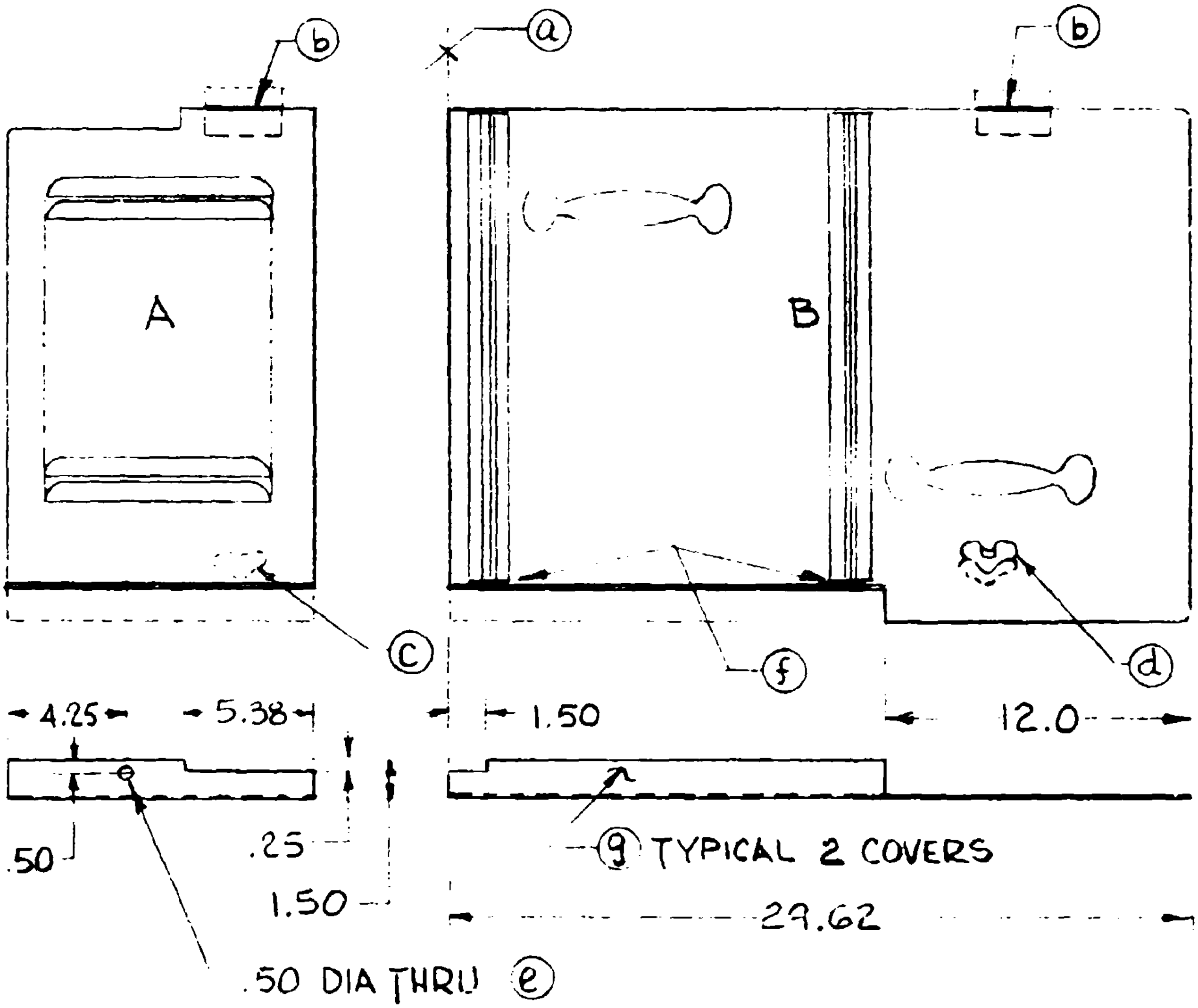


FLOODLIGHT BRACKET ATTACHMENT TO ROPS

FIGURE 11

ENGINE COVER ~ LEFT HAND, REWORK.

" " RIGHT HAND REWORK IDENTICAL
EXCEPT IDENTIFY AS COVERS C & D.



REWORK SEQJENCE

ⓐ CUT COVER INTO 2 COVERS A & B ON INDICATED LINE.

ⓑ RELOCATE SUPPORT HOOKS .62 LOWER (FLUSH WITH TO

ⓒ REMOVE LATCH HOOK, COVER A.

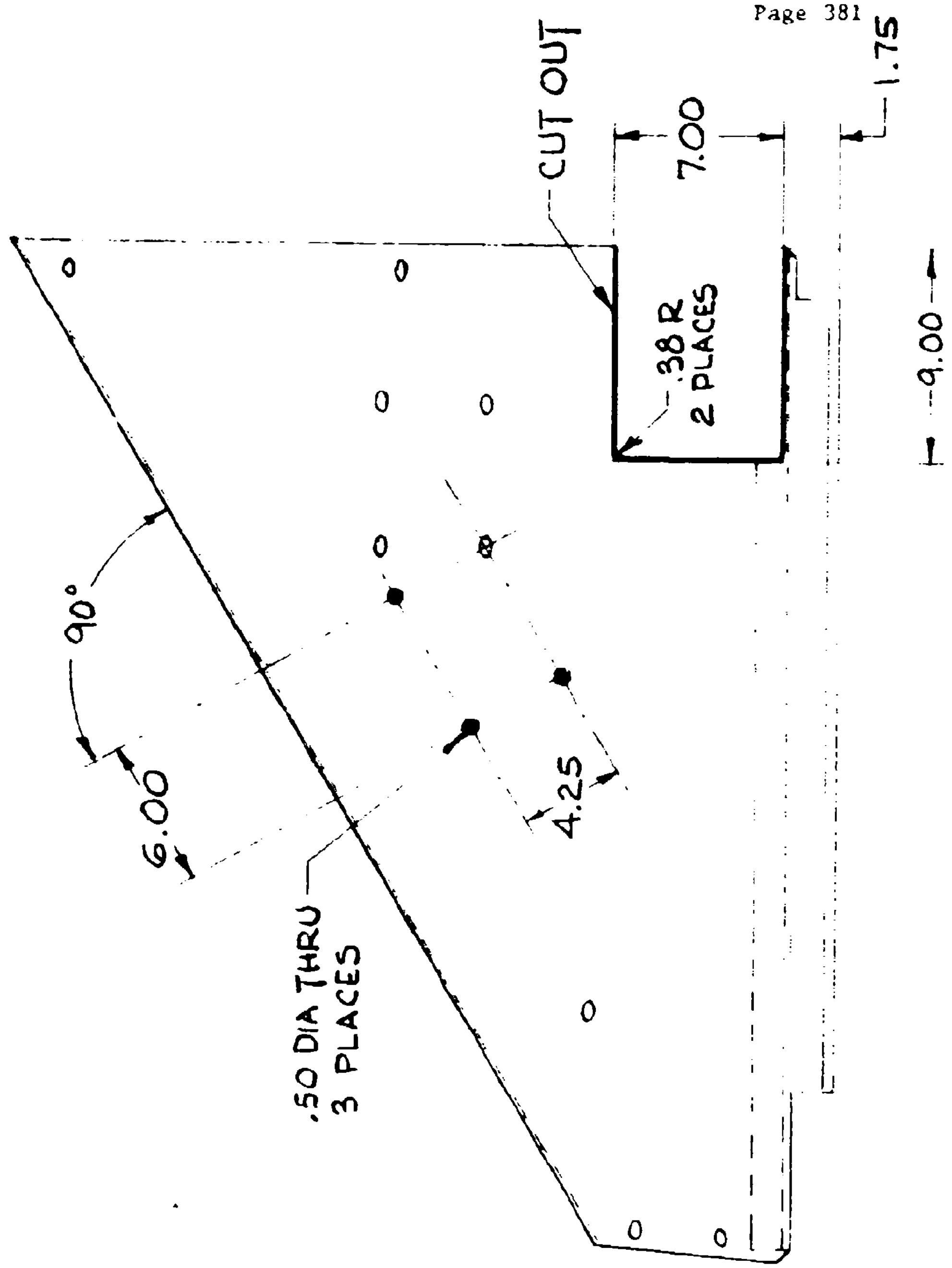
ⓓ RELOCATE LATCH HOOK .62 HIGHER, COVER B.

ⓔ DRILL HOLE.

ⓕ CUT OFF ENDS OF STIFFENERS BEFORE BENDING COVERS.

ⓖ CUT & BEND LOWER EDGE TO 90°. RETAIN WEBBING STRI

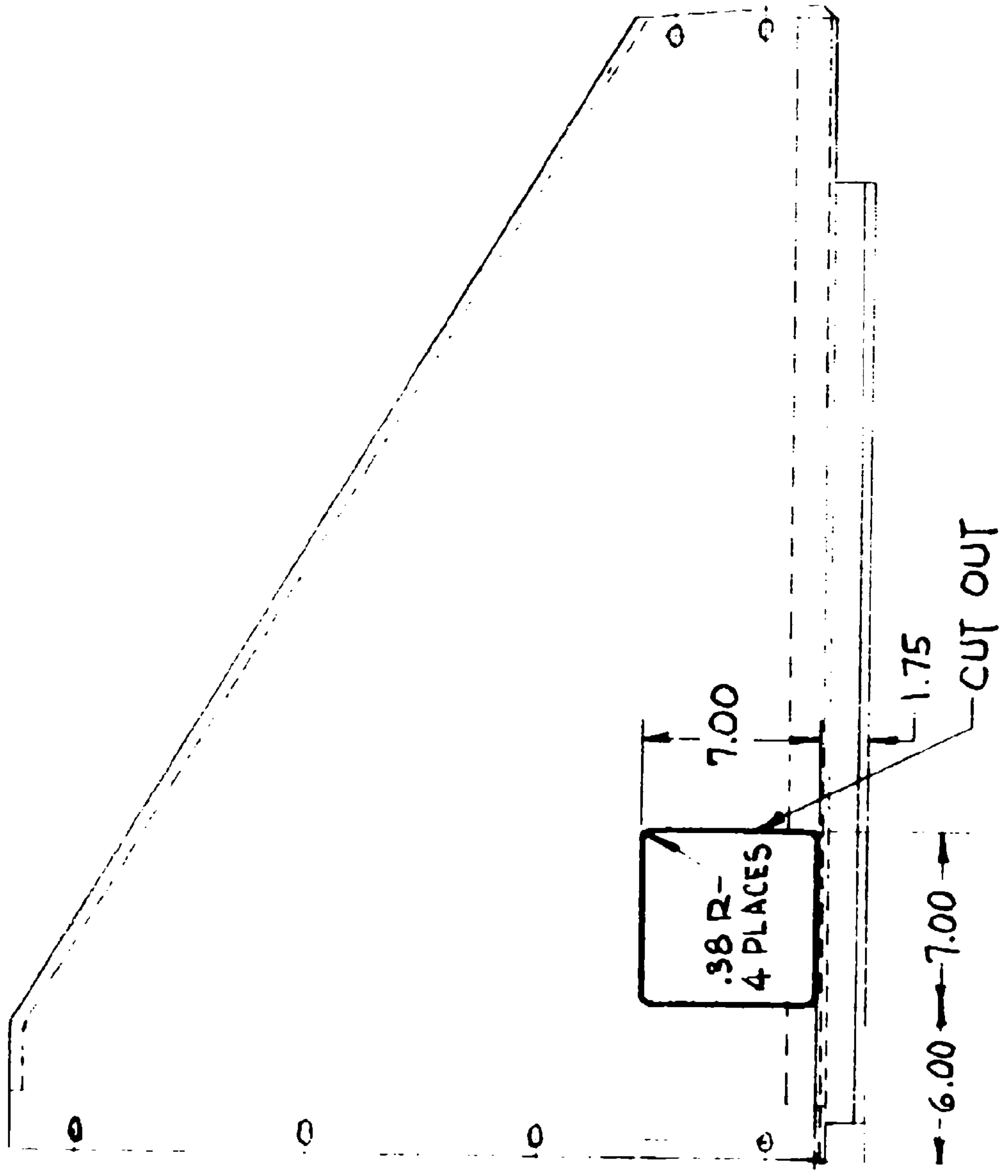
FIGURE 1



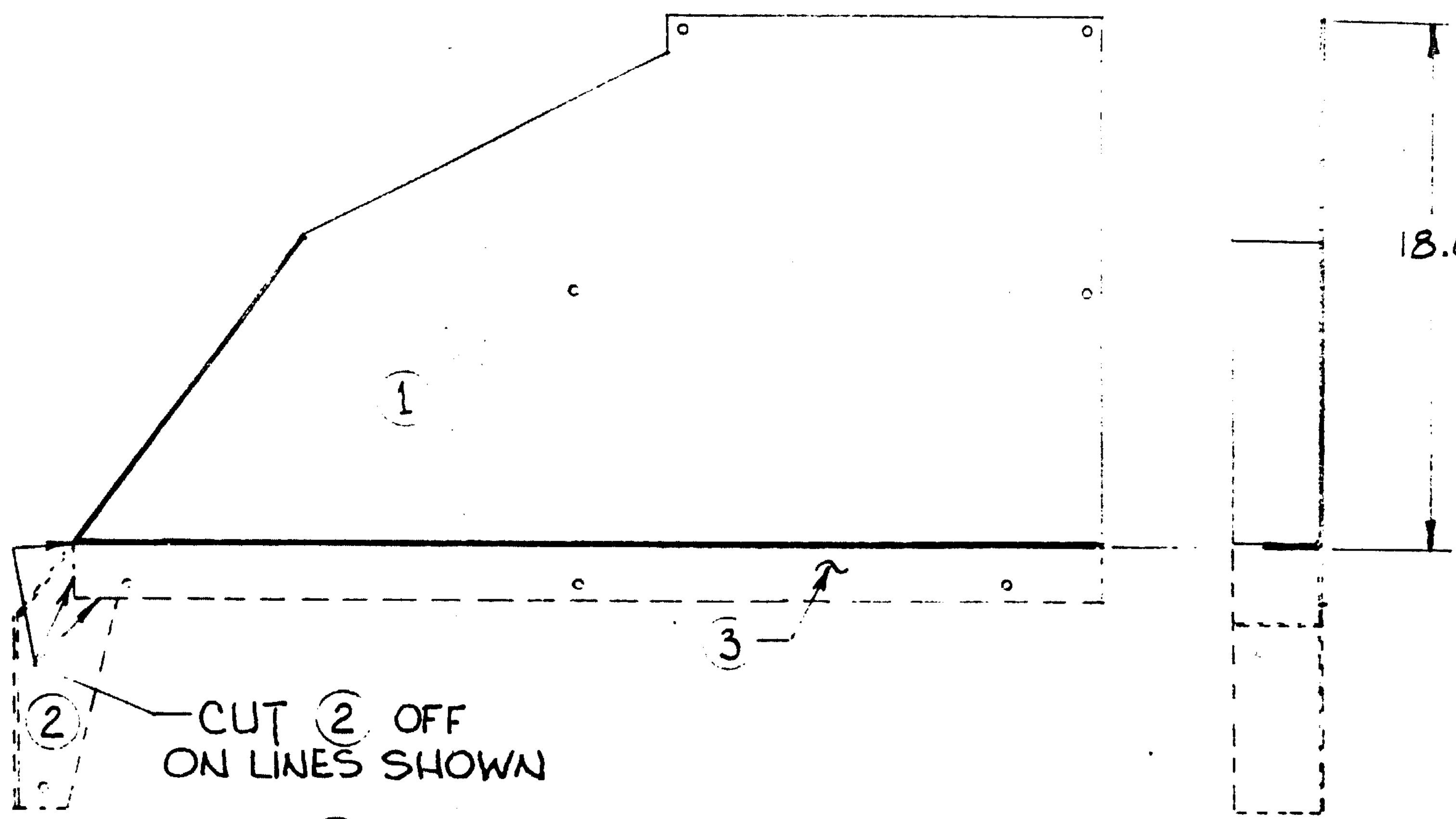
FENDER, LEFT REAR, REWORK

FIGURE 13

FIGURE 4



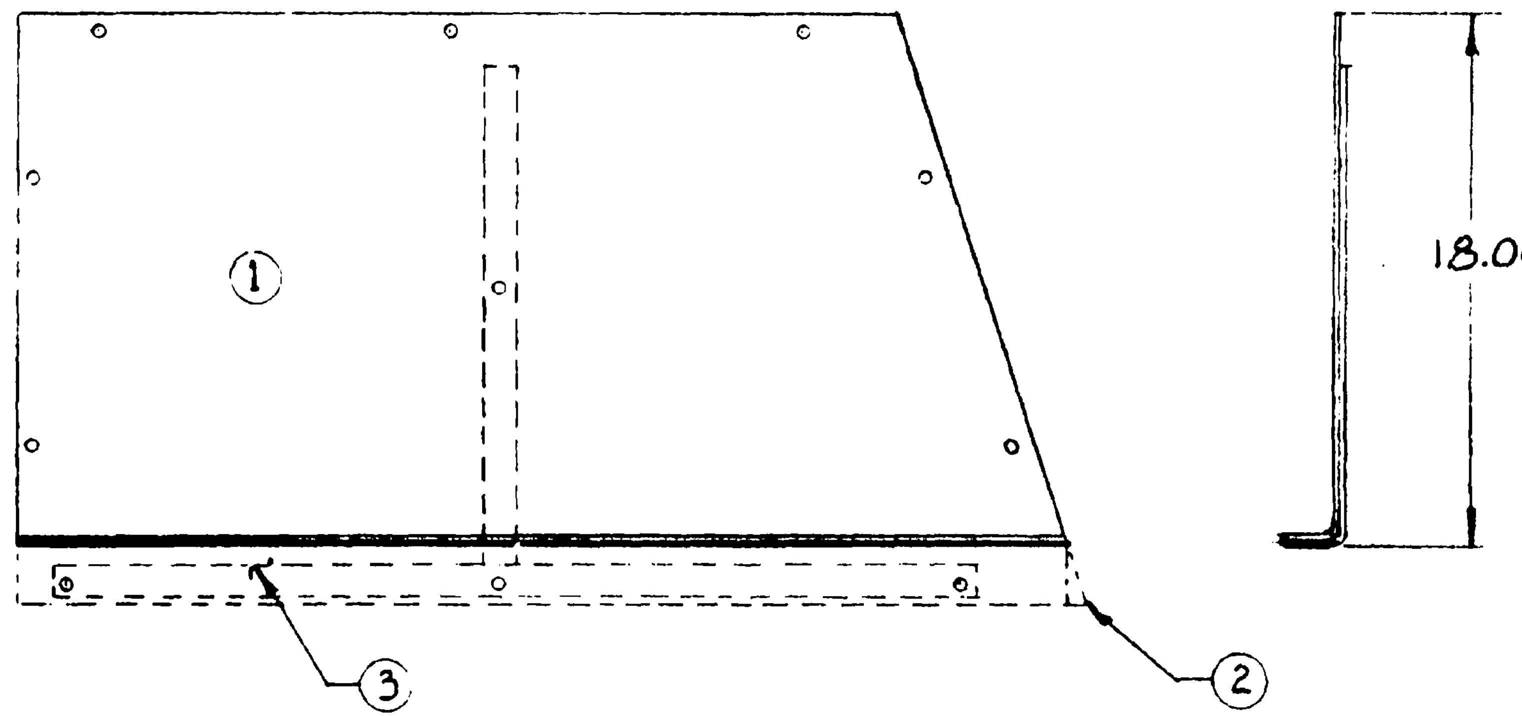
FENDER, RIGHT REAR, REWORK



BEND (3) UP AT 90° PER END VIEW

COVER, PANEL, LEFT HAND, REWORK

FIGURE 15



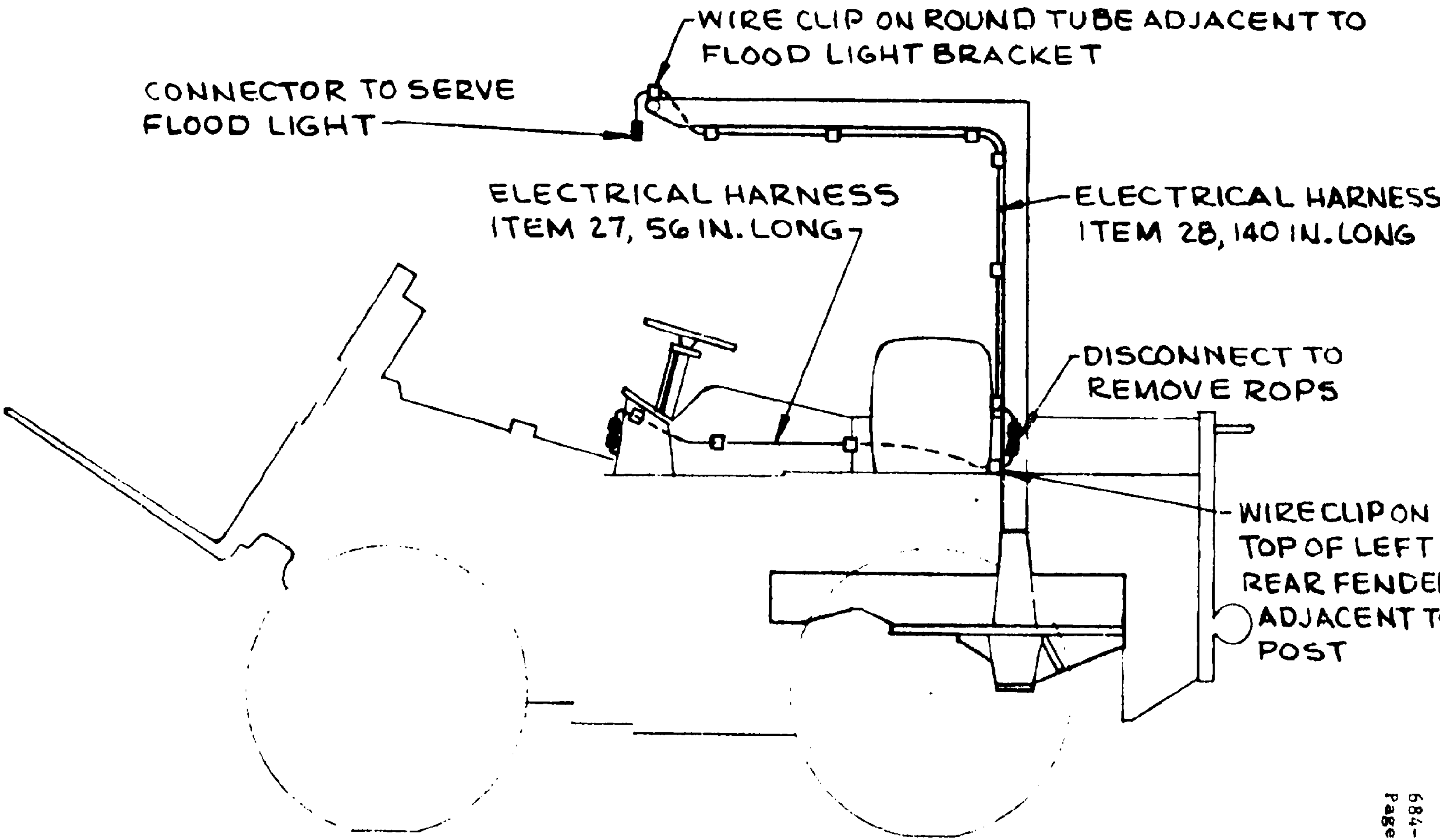
CUT CORNER 2 OFF SQUARE
BEND 3 UP AT 90° PER END VIEW

COVER, PANEL, RIGHT HAND, REWORK

FIGURE 16

10349

Figure 17. Resilient Pads in Place



ATTACH CLIPS WITH NO. 10 PAN HEAD SELF TAPPING SCREWS .75 LONG, NO. 10 FLAT WASHERS & NO. 10 LOCKWASHERS.

DRILL HOLES WITH NO. 10 DRILL (.1470 DIA)

INSTALLATION OF ELECTRICAL HARNESSES

ITEMS NO. 27 & 28

FIGURE: 8

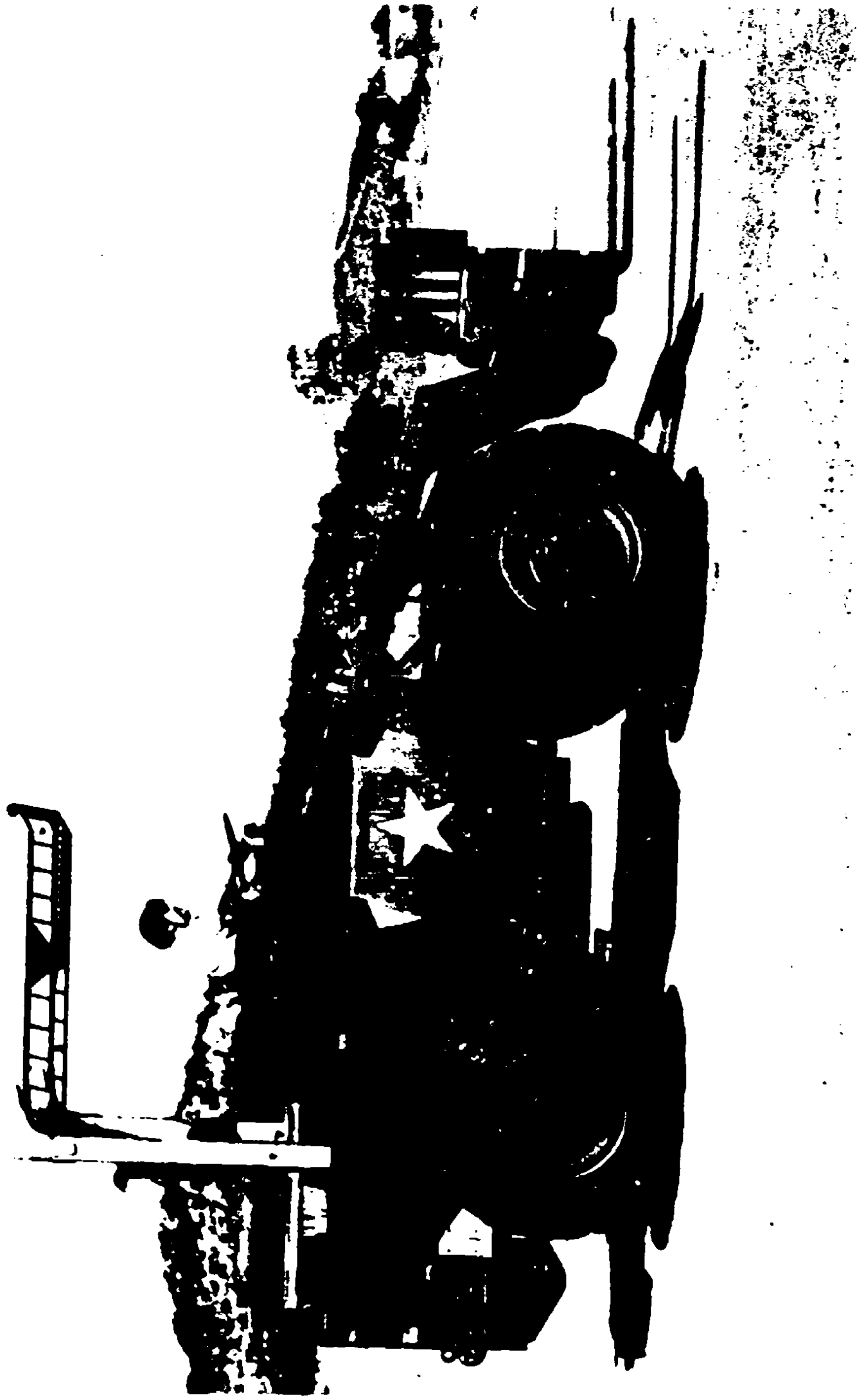


Figure 19. ROPS Installation Complete

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